Preliminary Thermal and Mineral Water Survey of Nisyros Volcano, Aegean Sea: A Study Targeted Towards Sustainable Development.

ZOUZIAS DIMITRIOS & ST. SEYMOUR KAREN
Department of Geology
University of Patras
Panepistimioupolis, Rion Patras, 26500
GREECE
dizouzias@upatras.gr http://www.geology.upatras.gr/ergastiria/koitasmatologia/home%20page.htm

Abstract: - Nisyros represents the ideal candidate of a Mediterranean volcano for a pilot study on sustainable development. Nisyros was a renown Loutropolis in the past for its baths used for medicinal purposes. In this work, we present a preliminary survey of the thermal and mineral waters of the island. We present chemical data revealing seawater and geothermal water mixing processes. The aim of this work is to evaluate the water character and include thermal and mineral waters of Nisyros volcano in the sustainable development plan proposed for the establishment of Nisyros to the status of a National Park and as an attraction pole for "alternative tourism". However, the use that agrees with the promotion of the volcano to a Natural Park with the consensus of the permanent inhabitants, is their use for baths and in Spa centers. This target will redirect economy towards "alternative tourism" and restore Nisyros to its ancient status of a renown Loutropolis.

Key-Words: Thermal-mineral waters, hydrochemistry, Spa, Nisyros, tourism, sustainable development.

1 Introduction

Hellas is endowed with numerous thermal and mineral springs [1, 2] due to volcanism and its unstable geodynamic pattern. Nisyros is an active calcalkaline volcano in the eastern extremity of the Quaternary Aegean Volcanic Arc, formed by subduction of Africa under Eurasia. Nisyros is characterized by a volcanic stratigraphy typical of stratovolcanoes, which is shown in Fig. 1.

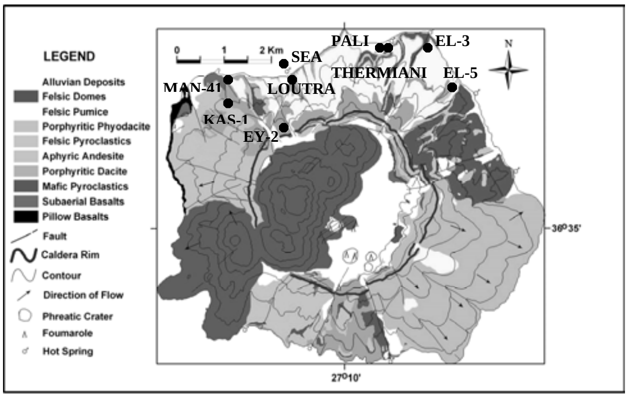

Fig. 1: Simplified geological map of Nisyros volcano (*black bullets* indicate sampling sites).

The active geothermal system at Nisyros is of high enthalpy [3] and consists of two reservoirs at different depths of which one occurs at relatively shallow depth (250-700m and 1500-1800m respectively; [3]). Two deep exploratory drillholes have been sunk on the caldera floor by Public Power Corporation of Hellas to evaluate the geothermal potential of Nisyros; however, further development has been prevented because the local population feels that such development will result in ecological disaster. Another expression of the active geothermal system on the island is its numerous thermal springs which are concentrated near the coastline due to intersection of steep terrain with tectonic and volcanotectonic faults (Fig. 2).

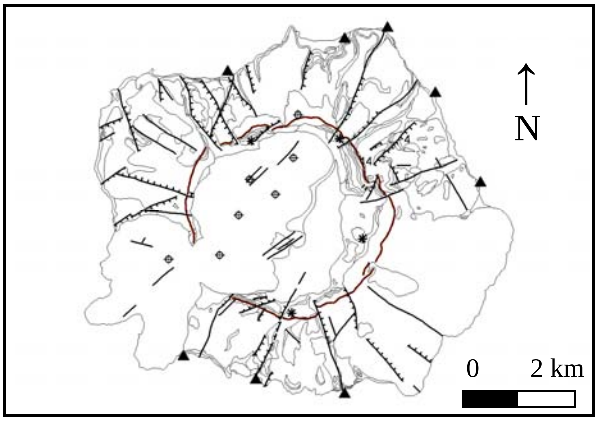

Fig. 2: Tectonic map of Nisyros with tectonic and volcanotectonic faults (*black lines*) and thermal springs near the coastline (*black triangles*).

Due to its thermal springs Nisyros was a renown Loutropolis in the past attracting visitors from many of the Mediterranean cities from the times of Hippocrates till the late 1800's.

2 Present Conditions

Nisyros (latitude 36° 35', longitude 27° 10') with a permanent population of 916 inhabitants, occupies one of the extremities of the "unfrequented ship line" of the Dodecanese Island Complex. The island is a rare natural monument of extreme beauty at the stage of neglect, which would have been severe in the absence of daily tourists from Kos and the international renewed scientific interest [4, 5, 6, 7, 8] in the area. We have proposed a three-pronged Sustainable Development Plan (Fig. 3; [9]) targeted towards the redirection of the economy towards *alternative tourism* with the development of thermal springs into Spa centers and *ecotourism* with the development of the volcano into a National Park. In this work we present hydrogeochemical survey data of the thermal and mineral waters of Nisyros to provide the scientific grounds for their re-establishment for medicinal purposes. That way their development would be given first priority in the Sustainable Development Plan for Nisyros volcano.

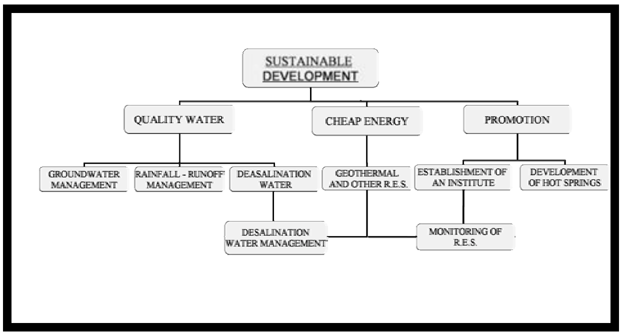

Fig. 3: Proposed plan of Sustainable Development of Nisyros volcano [9].

3 Sampling and Analytical Methods

A two period sampling survey has been carried out during 2006, one at the end of the "wet period" (end of May 2006) and another at the end of the "dry period" (end of October 2006). Additional sampling was repeated at the end of May 2007. A total of 24 samples for the three sampling periods (*wet-dry-wet*) have been collected from 9 sites, 9 from *thermal springs* (Loutra, Pali, Thermiani), 9 thermal water samples from *boreholes* (MAN-41, EL-5 and KAS-1), 5 *fresh water* samples from wells (EY-2 and EL-3) and one *seawater* sample (SEA) (Fig. 1). For the purpose of comparison EY-2, EL-3 and SEA as end-member compositions, as well as, chemical analyses from the literature of three known medicinal baths of the Aegean Volcanic Arc (Methana, Kammena Vourla and Aidipsos baths; [10, 11]. Electrode measurements of temperature, pH, T.D.S., electric conductivity and redox and measurements of alkalinity with the use of alkaline kit were performed in the field. Samples were subsequently filtered (0.45 μm), acidified with ultrapure nitric acid (acid level 0.2% or pH=2) and stored in screw top lid polyethylene vials. Chemical analyses were performed by the Activation Laboratories in Ontario, Canada, using ICP/MS and ICP/EOS for major and trace elements with detection limits 1μg/l for Li, Mg and Sc and 0.1mg/l for recalculated Mg, 0.1μg/l for Ti, V, Mn and Mo and 10μg/l for recalculated V, 0.5μg/l for Cr and Zn, 0.005μg/l for Co, 0.01μg/l for Cd and Pb, 0.2μg/l for Cu, Se and Hg, 0.03μg/l for As, 0.04μg/l for Sr and 10μg/l for recalculated Sr, 0.3μg/l for Ni, 2μg/l for Al, 3 μg/l for Br, 5 μg/l for Na and 0.1mg/l for recalculated Na, 10 μg/l for Fe, 30 μg/l for K and 0.1mg/l for recalculated K, 200μg/l for Si, 700μg/l for Ca and 0.1mg/l for recalculated Ca, 0.001μg/l for Th and U. Ion chromatography has been used for the determination of ions (F, Cl, Br, NO_2, NO_3, PO_4, SO_4) with detection limits 0.01mg/l for F, NO_2 and NO_3, 0.02mg/l for PO_4 and 0.03mg/l for Cl, Br and SO_4. The determination of NH_4 was carried out in the Laboratory of Hydrogeology, Department of Geology, University of Patras using the Salicylate method with detection limits 0.09mg/L NH_3–N in order to prevent further oxidation of NH_4 in our samples. Almost 90% of the samples display a mass balance below 5-7%.

4 Results

Our chemical data and data from the literature [10, 11] are listed in Tables 1-4. For a preliminary classification of the water samples, the results have been plotted in a Langelier-Ludwig diagram for all samples and sampling periods (Fig. 4). On the Langelier-Ludwig diagram all samples except fresh water samples (EY-2 and EL-3) are concentrated around seawater compositions. Samples KAS-1 display a decrease in Na^+ component as they are collected about 0.5 km away from the coastline at a depth of 90 m and an elevation of about 100 m hence seawater mixing seems to be lesser in this sampling location. EY-2 and EL-3 fresh water samples display a differentiation in the Na^+ component probably due to sample location of EY-2 (located at about 2 km away from the coast line; Fig. 1). Thermal springs of Kammena Vourla, Methana and Aidipsos plot near seawater composition and plot together with Pali, Loutra, MAN-41, EL-5 and Thermiani thermal water samples.

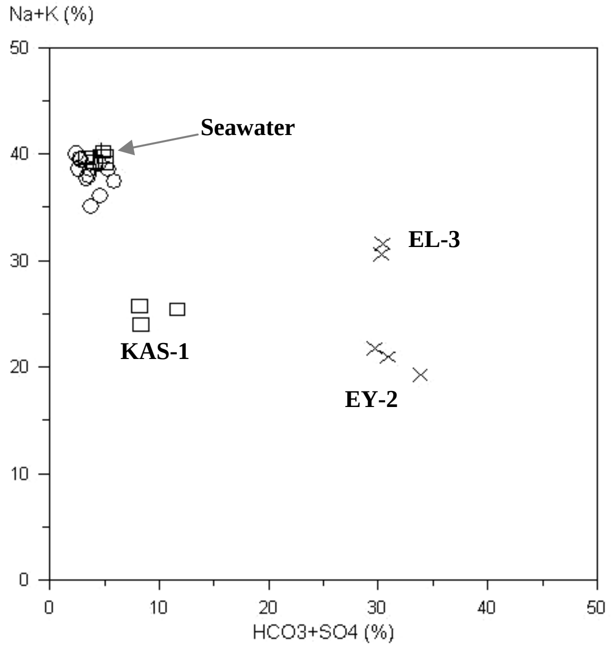

Fig. 4: Langelier-Ludwig diagram ("*wet-dry-wet period*" 2006-2007) for the thermal and mineral waters of Nisyros volcano and Kammena Vourla, Methana and Aidipsos thermal springs. (**x** represents fresh water samples, **open cycle** represents thermal springs, **open square** represents borehole thermal water samples and **cross** represents seawater).

The triangular diagram Cl-SO_4-HCO_3 (Fig. 5) display clearly, the *bicarbonate* character for EY-2 and EL-3 samples (cycle) and the *chloride* character of the rest of the samples (oval) including the thermal samples of the baths of Kammena Vourla, Methana and Aidipsos. The sample KAS-1 tends to be somewhat different from the rest of the samples which plot near the chloride apex (Fig. 5). KAS-1 reveals a slight enrichment in the *sulfate* component which may be attributed to: (a) increase of the ionic component on the ground waters with the longest path of circulation in the host rocks, which display initially saturation of the $CaSO_4$ followed by an increase in $SO^{=}_4$ and Ca^{2+} component. This is probably the case for KAS-1 which is taken 0.5 km away from the coastline (Fig. 1). A subsequent enrichment in Cl^- and Na^+ than in $SO^{=}_4$ and Ca^{2+} components is expected approaching the coastline as shown by the rest of the samples which plot near chloride apex and/or

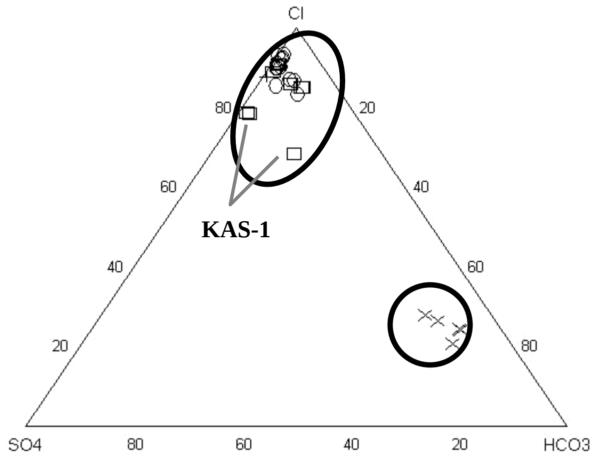

Fig. 5: Triangular diagram Cl-SO_4-HCO_3 showing bicarbonate (*cycle*) and chloride (*oval*) waters for Nisyros. (*Symbols as in figure 4*).

(b) increasing depth of circulation of thermal waters could prevent mixing with meteoric waters. This results in subsequent change of the chemical character as follows:

$$HCO_3^- \rightarrow HCO_3^- + SO_4^= \rightarrow SO_4^= + HCO_3^- \rightarrow SO_4^= + Cl^- \rightarrow Cl^- + SO_4^= \rightarrow Cl^- .$$

By plotting the Cl^- concentration against all other analyzed chemical constituents and comparing these plots to the simple mixing lines in Figure 6 we observe a general increase in Ca, K and Li and a decrease in Mg and SO_4 concentrations relative to seawater concentration. We attribute these changes to: (a) a decrease in the solubility of $CaSO_4$ due to the higher temperature of the thermal waters (b) to ionic exchange of Mg at high temperatures in several Ca– Mg– silicates in minerals and (c) to a general increase in Ca, K and Li possibly related to simple rock dissolution processes [12]. Samples from Pali, Kammena Vourla and Methana baths, plot close to the simple mixing line in Mg-Cl and SO_4-Cl diagrams, revealing seawater as one of the probable source of SO_4 and Mg for these samples (Figs. 6a, 6b). Sample KAS-1 displays an increase in SO_4 component compared to seawater in SO_4-Cl and Ca-Cl diagrams probably due to saturation of $CaSO_4$ (Figs. 6a, 6c). Departure from the mixing line for the rest of the samples indicates rock dissolution processes (Figs. 6a, 6b, 6c). Potassium is an element that prefers to partition in the hotter fluid, a preference displayed in the K-Cl diagram (Fig. 6d) which shows a general

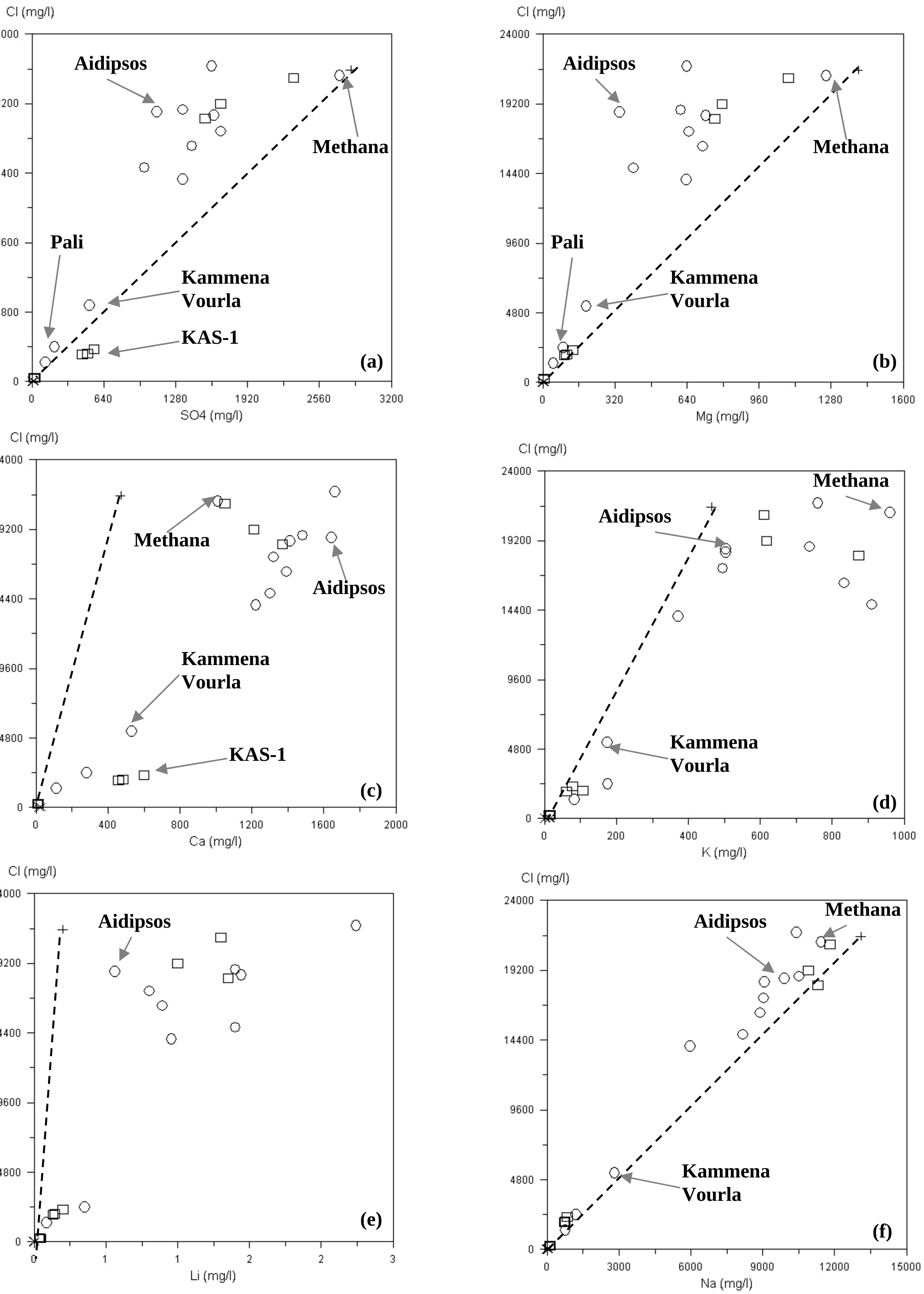

Fig. 6: Plots of Cl against the other analyzed components. Dashed-line represents the *simple mixing line* between ends members (**x** for fresh water and **+** for seawater), (*Symbols as in figure 4*).

increase in K for all thermal water samples. Lithium is a very mobile element and in thermal waters is an indicator of magmatic source participation, displaying a general increase in our samples (Fig. 6e). The ratio Na/Cl for most of our samples is close to the seawater ratio indicating seawater source for these elements (Fig. 6f). A slight variation from the mixing line could be due to rock dissolution and ion-exchange processes.

On a DUROV diagram (Fig. 7) we can distinguish three major groups. The first group (G1) comprises of fresh water samples displaying evidence of mixing and revealing a differentiation with respect to Ca^{+} and Na^{+} components probably due to sample location of EY-2 (located at about 2 km away from the coast line, Fig. 7). The second group (G2; Methana, Aidipsos, Kammena Vourla, Pali, Loutra, MAN-41, Thermiani) displays a Na-Cl hydrochemical character of waters that have reached the end of their hydrochemical history (Fig. 7). Relative to waters with Na-Cl chemical character, excess Ca^{2+} in the KAS-1 samples (G3) might be related also to reverse ion exchange processes (Fig. 7).

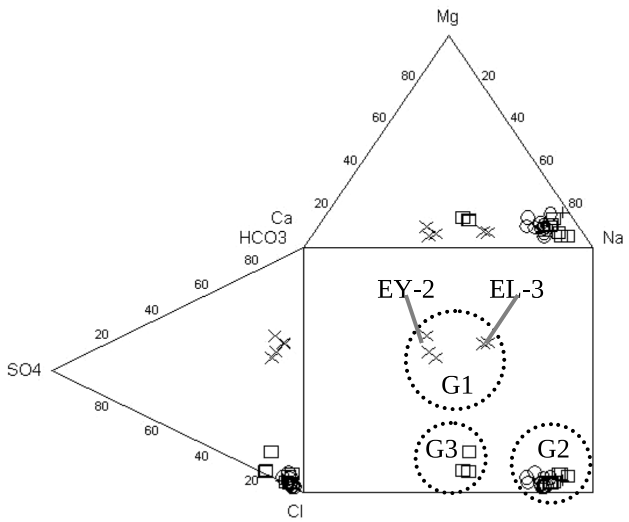

Fig. 7: DUROV diagram for the thermal and mineral waters of Nisyros volcano and Kammena Vourla, Methana and Aidipsos thermal springs (*Symbols as in figure 4*).

The seawater sample was collected in the vicinity of Loutra near the pumping station of the desalination installations. This sample displays very high values in V, Fe, Ni, Se, Mn and Co (Table 2) compared to their respective values in seawater ([13, 14). This could be explained by the presence of thermal submarine springs near the pumping point with waters enriched in these elements due to leaching of basaltic andesite bedrock.

5 Discussion

Medicinal waters are ground and/or spring waters that issue naturally or are extracted artificially, which have medicinal qualities due to their physical, chemical or radiological properties. *Thermal* and *mineral springs* qualify as medicinal waters. *Medicinal tourism* is a special type of tourism which is targeted towards the preservation, amelioration or healing of the psychosomatic health of a person without the use of medications or other type of therapeutic procedures. *Thermalism*, is a special type of tourism which encompasses a host of activities targeted towards the preservation or amelioration of the human well-being with the use of medicinal and/or sea waters, medicinal gases, mudbaths etc. These activities take place in especially built facilities which serve these purposes i.e. in *Spas*.

Thermal and mineral springs are characterized by temperatures over 19^{o}C, high values of total dissolved solids in the form of ions and gases. Mineral springs are considered to have values of Total Dissolved Solids (T.D.S.) over 1000mg/L. Thermal and mineral springs are characterized as *cold* (up to 20^{o}C), *hypothermal* (20^{o}-35^{o}C), *mesothermal* (35^{o}-50^{o}C) and *hyperthermal* (over 50^{o}C) [15]. According to their radioactivity, thermal springs are classified as *weak* (3.5-20 Mache), *moderate* (20-100 Mache) and *strong* (over 100 Mache). Thermal and mineral springs comprise of T.D.S. in the form of ions (Ce^{+3}, Br^{-}, SO_4^{-2}, HCO_3^{-}, J^{-}, F^{-}, Na^{+}, K^{+}, Li^{+}, Mg^{+2}, Fe^{+2}, Ba^{+}, Sr^{+}, Al^{+}, NH_4^{+}). and gases (N_2, CO_3, SO_4, CH_4, O_2, H_2S, He, Ne, Ar, Kr, Xe). The water type classification/profile of thermal and mineral springs is depended on the geology and particularly on the lithologies of an area. Higher temperatures increase the ability of leaching elements from the country rocks and increase the solubility potential of the thermal waters. According to their chemical profile they can be classified as *sulfide*, *sulfurous*, *bicarboniferrous*, *chlorine-sodium* and *ferric*.

The Geological Institute of Greece (I.G.M.E.) run a borehole project in the past in order to investigate the hydrogeological potential for fresh water for Nisyros island. However, no distinct fresh watertable was found due to mixing of thermal, meteoric and sea waters [16]. Mixing of hot geothermal waters with meteoric and sea water was also reported in an isotopic study targeted towards the geothermal assesment of Nisyros [17]. Mixing results in numerous thermal springs with

Table 1: Physical characteristics and chemical composition of major and trace elements of thermal, mineral and fresh waters from Nisyros volcano for the “wet period” of 2006

Analyte Symbol	T	pH	E.C.	eh	Alkaline	TDS	Na	Mg	K	Ca	Si	NH_4	NO_2	NO_3	HCO_3	SO_4	PO_4	Water Type
Unit Symbol	°C		μS/cm	mV	mg/L $CaCO_3$	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
EL-3	22	7.59	393	9	115	294	52.8	3.63	14.1	27.8	9.4	0	0.03	17.51	140.3	15.6	0.88	Na-Ca-HCO_3-Cl
EL-5	26.5	6.11	928	93	150	629	131	4.42	12.9	9	7	0.05	0.05	0.44	18.3	25.2	1.8	Na-Cl
EY-2	19.5	7.27	165.8	28	45	130	17.2	1.44	2.13	18.5	2	0	0.23	0.73	54.9	11.3	0.03	Ca-Na-HCO_3-Cl
KAS-1	29.2	6.84	6720	52	350	Over	706	95.6	60.1	457	65	3.35	0.5	3.21	427	450	0.92	Na-Ca-Cl
MAN-41	31.5	5.72	58100	95	220	Over	11300	762	873	1370	82	1.85	0.5	2.2	268.4	1540	3.06	Na-Cl
PALI	19.2	7.86	15600	-4	140	Over	1200	90	175	280	41	0.01	0.66	13.2	170.8	198	1.22	Na-Cl
THEMIANI	19.2	7.85	40500	-4	280	Over	8890	709	833	1390	70	0.08	1.65	61.6	341.6	1420	3.06	Na-Cl
LOUTRA	27.4	7.26	41400	28	145	Over	8170	402	910	1300	95	0.05	1.65	30.8	176.9	998	4.59	Na-Cl

Analyte Symbol	Li	Sc	Ti	V	Mn	Fe	Co	Ni	As	Se	Cd	Pb	Th	U	F	Zn	Sr	Br	Cl
Unit Symbol	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	mg/L	mg/L	mg/L	mg/L	mg/L
EL-3	2	2	2.2	4.9	0.9	-	0.053	0.7	1.83	0.6	0.03	0.1	-	0.337	0.01	0.02	0.05	0.1	50.4
EL-5	40	5	2	0.5	452	5800	1.68	7	0.15	1	0.5	0.05	0.89	0.005	0.54	12.7	0.06	0.77	268
EY-2	1	-	0.2	2.8	0.9	-	0.04	0.5	0.62	-	0.06	0.08	-	0.041	-	-	-	-	25.5
KAS-1	130	10	9	17	47	50	0.5	14	6.5	1	2.4	1.8	1.02	0.03	0.15	4.89	1.79	13	1900
MAN-41	1350	20	15	0.5	1080	11300	3.07	134	87.8	26	0.3	0.2	0.97	0.2	0.5	-	17.6	63	18200
PALI	350	5	7	24	3	50	0.1	9	38.8	29	0.2	0.2	0.86	1.51	0.2	0.05	4.69	7.8	2430
THERMIANI	890	20	12	0.5	1	50	0.12	124	42.2	1	0.9	0.05	0.86	0.52	0.5	-	13.8	56	16300
LOUTRA	1400	20	14	0.5	749	50	0.4	294	269	1	0.3	0.05	0.87	0.33	0.5	0.06	14.3	49	14800

.

Table 2: Physical characteristics and chemical composition of major and trace elements of thermal, mineral, fresh and seawater from Nisyros volcano for the “dry period” of 2006.

Analyte Symbol	T	pH	E.C.	eh	Alkaline	TDS	Na	Mg	K	Ca	Si	NH_4	NO_3	NO_2	HCO_3	SO_4	PO_4	Water Type
Unit Symbol	^oC		μS/cm	mV	mg/L CaCO3	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
EL-3	23.7	8.07	433	-17	115	309	55.9	3.39	15.4	27.4	9.3	0	17.91	-	140.3	15.6	0.52	Na-Ca-HCO_3-Cl
EL-5	35.2	6.32	1064	85	20	611	101	4.46	16.1	9.9	8	0.27	0.22	0.03	24.4	19	0.05	Na-Cl
EY-2	20.9	7.68	190.9	8	50	145	15.2	1.12	2.37	18.1	1.8	0	1.8	0.03	61	10.4	0.06	Ca-Na HCO_3-Cl
KAS-1	32.9	6.9	7560	52	30	Over	743	105	106	483	70	0	7.04	0.16	268.4	494	0.46	Na-Ca-Cl
MAN-41	34.7	5.76	61100	117	220	Over	10900	795	617	1210	70	1.6	2.2	1.65	268.4	1680	3.06	Na-Cl
PALI	21.4	7.56	4190	14	65	Over	740	45.4	82.9	113	16	0.01	7.04	0.16	79.3	118	0.3	Na-Cl
THERMIANI	23.8	7.73	45800	5	185	Over	9030	684	495	1320	60	0	88	3.3	225.7	1680	6	Na-Cl
LOUTRA	39.2	7.13	85800	38	200	Over	10500	611	736	1480	80	1.35	17.6	3.3	244	1340	4.59	Na-Cl
SEA	22.5	7.88	56500	-3	145	Over	13100	1400	465	470	-	0	4.4	3.3	176.9	2840	12.24	Na-Cl

Analyte Symbol	Li	Sc	Ti	V	Mn	Fe	Co	Ni	As	Se	Cd	Pb	Th	U	F	Zn	Sr	Br	Cl
Unit Symbol	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	mg/L	mg/L	mg/L	mg/L	mg/L
EL-3	3	2	2.4	7	0.4	-	0.057	0.8	2.19	0.5	0.02	0.15	-	0.35	0.04	0.007	0.06	0.13	49.4
EL-5	34	2	0.9	-	498	2580	1.81	3.8	-	3.6	0.44	0.16	0.006	-	0.59	9.96	0.06	0.75	246
EY-2	2	-	0.3	3.7	2.9	-	0.042	1	1.46	0.5	0.02	0.07	-	0.07	-	0.017	0.04	0.08	25.5
KAS-1	143	15	7.8	23	18.1	-	0.31	19.6	12.6	26	1.69	0.72	0.001	0.006	0.3	2.82	2.24	6.7	1960
MAN-41	1000	50	20	5	1240	7000	4.4	60	99	160	-	0.5	0.05	0.2	0.5	0.025	15	64	19200
PALI	84	3	2	11	1.1	-	0.034	7.3	10.9	15.1	0.09	0.08	-	0.059	0.05	0.01	0.88	4.5	1340
THERMIANI	800	50	5	60	5	500	0.25	40	77	160	-	0.5	0.05	0.4	1	0.025	13.3	54	17300
LOUTRA	1400	50	20	5	4920	500	4.2	40	339	170	0.5	0.5	0.05	0.2	1	0.025	17.7	64	18800
SEA	200	50	5	5	5	500	0.25	220	34	210	0.5	0.5	0.05	3.6	1	0.025	8.62	74	21500

Table 3: Physical characteristics and chemical composition of major and trace elements of thermal, mineral, fresh and seawater from Nisyros volcano for the "wet period" of 2007.

Analyte Symbol	**T**	**pH**	**E.C.**	**eh**	**Alkaline**	**TDS**	**Na**	**Mg**	**K**	**Ca**	**Si**	**NH_4**	**NO_3**	**NO_2**	**HCO_3**	**SO_4**	**PO_4**	**Water Type**
Unit Symbol	**°C**		**μS/cm**	**mV**	**mg/L CaCO3**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	
EY-2	23.4	7.94	239	8	-5	175	22	3.08	2.63	27.5	3.5	0	4.48	0.06	85.4	13.5	0.03	Ca-Na HCO_3-Cl
LOUTRA	43.5	6.78	71300	38	59	over	10400	637	759	1660	87.9	1.07	14.52	3.3	25.6	1600	4.59	Na-Cl
PALI	27.3	6.94	36200	14	46	over	5970	635	371	1220	51.7	0	53.68	3.3	244	1340	4.59	Na-Cl
EL-5	35.9	6.50	1007	85	76	575	129	4.45	15.3	12.3	9.7	0.66	4.88	0.03	24.4	17.6	0.046	Na-Cl
MAN-41	33.7	5.74	65500	117	119	over	11800	1090	610	1050	71.2	1	4.4	3.3	280.6	2330	6.12	Na-Cl
THERMIANI	27.4	7.57	48600	5	13	over	9070	722	503	1410	68.1	0	72.16	3.3	183	1620	4.59	Na-Cl
KAS-1	35.7	8.79	8790	52	60	over	833	132	77.2	599	71.8	0.14	8.71	0.49	61	553	0.76	Na-Ca-Cl

Analyte Symbol	**Li**	**Sc**	**Ti**	**V**	**Mn**	**Fe**	**Co**	**Ni**	**As**	**Se**	**Cd**	**Pb**	**Th**	**U**	**F**	**Zn**	**Sr**	**Br**	**Cl**
Unit Symbol	**μg/L**	**μg/L**	**μg/L**	**μg/L**	**μg/L**	**μg/L**	**μg/L**	**μg/L**	**μg/L**	**μg/L**	**μg/L**	**μg/L**	**μg/L**	**μg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
EY-2 IC	4	0.5	0.3	3.5	1.1	-	0.04	0.8	1.27	0.4	0.01	0.2	-	0.083	0.05	0.018	0.05	0.07	25.6
LOUTRA IC	2240	50	17.1	48.3	3940	500	2.82	36	356	72.3	-	1.4	0.05	0.272	1	0.105	18.2	79	21800
PALI IC	955	50	12.3	55.3	35.1	2280	5.42	30.6	36.6	52	1.08	3.23	0.05	1.33	1	0.128	11.3	48	14000
EL-5 IC	43	5	-	-	535	1840	2.07	5.3	-	2.9	0.27	0.6	-	-	0.62	12700	0.07	0.78	237
MAN-41 IC	1300	50	19.8	-	1790	6270	6.63	93.2	-	-	-	7.1	0.05	0.315	1	0.137	14.4	75.4	21000
THERMIANI IC	1440	50	26.7	42.4	19	500	-	36.9	28.2	-	-	2.96	0.05	0.536	1	0.295	14.2	64.4	18400
KAS-1 IC	198	50	-	34.1	167	500	0.84	-	7.17	20.7	3.45	2.88	0.05	0.113	-	6.920	2.64	7.87	2220

Table 4: Physical characteristics and chemical composition of major and trace elements of thermal water samples from Kammena Vourla, Methana and Aidipsos baths of the Aegean Volcanic Arc ([10, 11]).

Analyte Symbol	**T**	**Na**	**Mg**	**K**	**Ca**	**HCO_3**	**SO_4**	**Br**	**Cl**	**Water Type**
Unit Symbol	**^oC**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	
KAMMENA VOURLA [10]	32.7	2805.1	190.5	173.2	530.9	546.1	511.3	-	5282	Na-Cl
METHANA [10]	34.4	11420	1257.8	960.5	1008.3	849.3	2738.7	53	21148	Na-Cl

Analyte Symbol	**T**	**pH**	**Na**	**Mg**	**K**	**Ca**	**NH_4**	**HCO_3**	**SO_4**	**PO_4**	**Li**	**Mn**	**Fe**	**Br**	**Cl**	**Water Type**
Unit Symbol	**^oC**		**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**ug/L**	**ug/L**	**ug/L**	**mg/L**	**mg/L**	
AIDIPSOS [11]	83	6.63	9887	338.4	503.3	1642.5	1.1	197.9	1111	0.03	360	13	7500	55.8	18640	Na-Cl

mesothermal-hyperthermal waters (40^o-50^oC; [17]), which issue around the coasts of the island (Fig. 8).

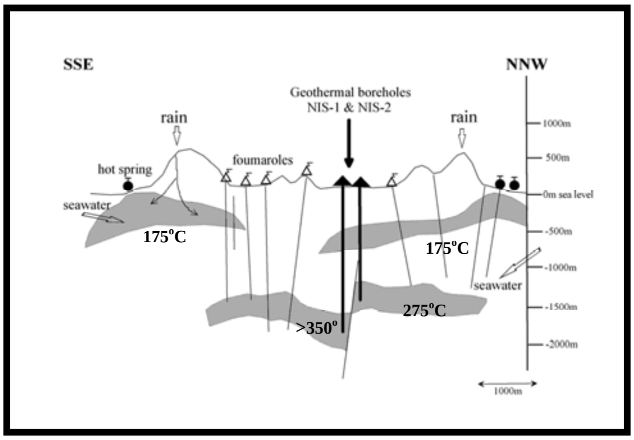

Fig. 8: Schematic hydrological model of thermal-fluid fluid subsurface flow at Nisyros (grey color indicates the geothermal reservoirs; *After Kavouridis et al. 1999* [17])

For this reason, Nisyros was selected by the Father of Medicine, Hippocrates, for its baths and was a renown Loutropolis during Roman times and even more recently during the late 1800's A.D. Presently an effort has been made to re-establish the baths in the vicinity of Loutra. The *Loutra Baths* are supplied by a natural spring that provides mesothermal-hyperthermal waters of about 50^oC collected in a cistern to cool to a desirable temperature for bathing. The facilities at Loutra offer a capacity of 65 beds and they are open to the public from May to October. Our chemical analyses indicate that Loutra Baths are supplied by Na-Cl-(K-Br) mineral waters which can be classified as *sulphurous* (Tables 1-3). Two other very well known *sulphurous* bath sites in Nisyros are the *Thermiani* and *Pali Baths* (Fig. 9; Tables 1-3).

Fig. 9: View of the front of the Pali Baths in Nisyros.

The natural spring of Thermiani was the ancient baths of Hippocrates. Thermiani nowadays is occupied by the church Panagia Thermiani with no further development. The Pali Baths is hosted in an exquisite stone building which is extremely well organized for bath function and as a Spa center (Fig. 9). However, its development has been arrested due to litigation procedures.

"*One should be aware of the power of waters; because as they vary in taste and origin, their healing powers may vary as well*" [10, 18]. Spa treatment could represent the first alternative choice to drugs in chronic, nonresponsive inflammatory diseases. Medical treatment is offered in the Greek spas for rheumatisms, arthritic diseases, respiratory disorders, gastroenterological problems and gynaecological and circulatory diseases. For the dermatologic disorders, sulfurous spa waters are the most appropriate. *In vitro* studies have shown that sulfurous water can inhibit the proliferation of normal lymphocytes and T cells obtained from patients with chronic immunomediated diseases [10, 19]. Also, it was reported that sulphurous spa waters can inhibit ILL and IFNy release from TH1 lymphocytes, suggesting that immersion in sulphurous water can modulate some physiopathological aspects of the memory T-lymphocyte cells [10, 19, 20]. Some of the most well known Greek spas with sulfurous waters are the spas of Aidipsos, Kammena Vourla and Methana. Patients from Greece and abroad suffering from arthritis, rheumatisms, psoriasis, atopic dermatitis and various types of eczema visit these spas annually to complement the treatment of their disease. Thermiani, Loutra and Pali baths, as well as, MAN-41 and KAS-1 are sulfurous in character ranging mainly from 450-2300 mg/l in SO_4 (Tables 1-3) and display similar hydrochemical patterns with Aidipsos, Kammena Vourla and Methana spas (Figs. 4, 5, 6, 7). In addition, Thermiani was the ancient baths of Hippocrates and Loutra and Pali baths were in operation during the late 1800's A.D. Loutra are partly operational at the present time. Establishing the chemical character of Nisyros thermal waters and comparing it to the chemical character of waters from fully operational Hellenic spas is the first prerequisite for their registration in the National Catalogue of Thermal and Mineral Springs of Greece. This will provide the first step towards their further development to spas. Spa centers create an attraction pole for "alternative tourism" such as ecotourism and thermalism. Alternative tourism will provide a launching pad for setting Nisyros successfully to a sustainable development orbit. Further investigation of the origin, circulation and mixing mechanisms of the Nisyros thermal waters requires collection of radon and isotopic data which is presently underway. Evaluation of their general chemical character and trace element profiles will be used for comparison with balneological data bases.

6 Acknowledgements

We thank Mr. *George Papaioannou* for assistance during water sampling surveys; the *Laboratory of Hydrogeology, Department of Geology, University of Patras, Greece* for supplying lab facilities and field equipment; the *Municipality* and the *inhabitants* of Nisyros for their kind co-operation during field surveying.

References:

[1] Giono-Stavropoulou G. Inventory of thermal-mineral springs of Greece – Aegean Sea. *I.G.M.E.* Athens, 1983.

[2] Sfetsos C.S. Inventory of thermal-mineral springs of Greece – Mainland of Greece. *I.G.M.E.* Athens 1988.

[3] Geotermica Italiana, Nisyros 1, 2 geothermal well. *PPC-EEC report*, 1983-1984.

[4] Karen St. Seymour, and A. Lalonde. Monitoring Oxygen fugacity conditions in pre-, syn- and postcaldera magma chamber of Nisyros Volcano, Aegean island Arc, Greece. *Journal of Volcanology and Geothermal Research 46: 231-240*,1991.

[5] Karen St. Seymour, Georges Denes and Michael Townsend. An unusual palagonite from Nisyros calcalkaline volcano. *Neues Jahrbuch fur Mineralogie Abh: 165, 2, 111-121*, 1993.

[6] Karen St. Seymour and Dimitri Vlassopoulos. Magma Mixing at Nisyros Volcano as Inferred from Incompatible Trace Element Systematics. *Journal of Volcanology and Geothermal Research*: *50, 273-299*, 1992.

[7] Dimitrios Zouzias and Karen St. Seymour. Magma intrusion in proto-caldera systems. Example from the Nisyros volcano. *12th Hellenic Geological Society International Conference, Athens 2007.*

[8] Lagios, E., Sakkas, V., Parcharidis, Is. and Deitrich, V.. Ground deformation of Nisyros volcano (Greece) for the period 1995-2002: Results from DInSAR and DGPS observations. *Bulletin of Volcanology*, 68, 201-214, 2005.

[9] Zouzias, D. and St.Seymour, K., Reviving the dream: a pilot project on sustainable development of Nisyros volcano, *International Conference*, *IESCA2005* (International Earth Sciences Colloquium on the Aegean Regions), 4-7 October, Izmir, Turkey, 2005.

[10] Katsambas, A. and Antoniou, C. Mineral water and Spas in Greece. *Clinics in Dermatology 14, 615-618*, 1996.

[11] http://www.healthy-stuff.co.uk/holidays.aspx

[12] Minissale A., Duchi V., Kolios N., Nocenti M. and Verruchi C., Chemical patterns of thermal aquifers in the volcanic islands of the Aegean Arc, Greece, *Geothermics*, 26, 501-518, 1997.

[13] Karl K Turekian: *Oceans*. Prentice–Hall, 1968.

[14] www.seafriends.org.nz/oceano/seawater.htm

[15] Kallergis G., Applied Hydrogeology, *Academic Publications*, 2005.

[16] Vitoriou A., Hydrogeological investigation of the aquifers of the island of Nisyros, Greece, *I.G.M.E. report*, 1986.

[17] Kavouridis, T., Kuris, D., Leonis, C., Liberopoulou, V., Leontiadis, J., Panichi, C., La Ruffa, G. and Caprai, A. Isotope and chemical studies for a geothermal assessment of the island of Nisyros (Greece). *Geothermics 28, 219-239*, 1999.

[18] Pournaropoulos G. On winds, waters and places, Hippocrates. *Collected Works*. LB, 12-3. 1937.

[19] Valituttus S, Costellino F, Musiani P. Effect of sulphureous "thermal" water on T lymphocytes proliferative response. *Ann Allergy* 65:463-68. 1990.

[20] Simonelli C. Come le acque sulfuree modulano il sistema immunitario. *Current* 1(1):15-5. 1994.