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GEOLOGICAL STUDY FOR A WETLAND RESTORATION: THE CASE OF THE DRAINED MOURIA LAKE (W. PELOPONNESE)

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Abstract

The Mouria Lake was drained for cultivation during late 1960's. A 0.5-ha large pilot-scale wetland is now constructed in order to study the sedimentological lake-restoration aspects. The uppermost horizons (up to 3 m thick) consist of fine sediments (mud, silt, clay) of fluvial origin, deposited in a lacustrine environment and constituting the lagoonal bottom material, which extents all over the area ever covered by the original Mouria Lake. A sand layer (3 m beneath the current surface) constitutes the substrate of the lagoonal bottom revealing a higher energy deposition environment in comparison to the overlying fine sediments. High pH and electric conductivity values reveal strong alkaline environment and high content of dissolved solids, respectively. The sediments reveal high CEC, as a result of high clay minerals content. Other main mineral phases that occur include quartz, feldspars and calcite. The weathering of marginal rocks is the major factor controlling the mineralogical-geochemical composition of the sediments. The strong alkaline features of the sediments inhibit trace element mobilization. Continuous monitoring of the chemical composition is necessary in order to predict and prevent a possible mobilization of hazardous trace elements and the subsequent release to the environment.
Key words: *Re-flooding, depositional environment, mineralogical composition, geochemical composition.*

Περίληψη

Η Λίμνη Μουριά αποξηράνθηκε στα τέλη της δεκαετίας του 1960, λόγω των αυξημένων αναγκών για καλλιεργήσιμες εκτάσεις. Στην παρούσα μελέτη εξετάζονται τα ιζηματολογικά χαρακτηριστικά μίας μικρής έκτασης της πρώην λίμνης, στην οποία κατασκευάστηκε μία πιλοτική λίμνη. Οι ανώτεροι ορίζοντες (πάχους περίπου 3 m) αποτελούνται από λεπτόκοκκο υλικό ποτάμιας προέλευσης, που αποτέθηκε σε λιμναίο περιβάλλον, σχηματίζοντας το λιμνοθαλάσσιο πυθμένα που εκτείνεται σε όλη την περιοχή της αποξηραμένης λίμνης. Σε βάθος 3 m απαντάται στρώμα άμμου, το οποίο αποτέθηκε σε περιβάλλον υψηλής ενέργειας και αποτελεί το υπόβαθρο του λιμνοθαλάσσιου πυθμένα. Τα ιζήματα χαρακτηρίζονται πολύ έντονα αλκαλικά με υψηλή περιεκτικότητα σε διαλυμένα στερεά. Η υψηλή ικανότητα ιοντοανταλλαγής (CEC) οφείλεται αποκλειστικά στην παρουσία αργιλικών ορυκτών. Χαλαζίας, άστριοι, αργιλικά ορυκτά και ασβεστίτης είναι τα κύρια ορυκτολογικά συστατικά. Η ορυκτολογική και γεωχημική

σύσταση των ιζημάτων οφείλεται κυρίως στην αποσάθρωση των περιβαλλόντων σχηματισμών. Οι έντονα αλκαλικές συνθήκες (υψηλό pH), που επικρατούν στα ιζήματα της περιοχής, δρουν ανασταλτικά στην κινητικότητα των ιχνοστοιχείων. Απαιτείται συνεχής παρακολούθηση της χημικής σύστασης των ιζημάτων της πιλοτικής λίμνης, γιατί ενδεχόμενη μεταβολή των συνθηκών που επικρατούν σήμερα, θα διαταράξει την ισορροπία του συστήματος της πιλοτικής λίμνης προκαλώντας ενδεχόμενα αύξηση της κινητικότητας των ιχνοστοιχείων και αποδέσμευσή τους στο περιβάλλον.
Λέξεις κλειδιά: *Επαναπλημμυρισμός, περιβάλλον απόθεσης, ορυκτολογική σύσταση, γεωχημική σύσταση.*

1. Introduction

In the early 1920's, several wetlands were drained in Northern Greece, in order to provide agricultural land to refugees from Asia Minor, as well as to protect the health of local population against malaria (Psilovikos, 1992; Bouzinos et al., 1994; Christanis, 1996). This practice was applied in the next decades all over the country until late 1960's when the last lakes were drained, namely these of Mouria and Agoulinitsa in Western Peloponnese. The areas of both lakes were converted into urban and agricultural land (Manariotis and Yannopoulos, 2004; Sofikitis et al., 2007; Chatziapostolou et al., 2008) (Figure 1a).

The Mouria Lake was located approximately 5 km WSW from Pyrgos town (Prefecture of Ileia), at the northwest of Alfeios River delta (Figure 1a, b). Through two narrow openings to the sea side seawater entered the lake creating brackish water conditions, Today the c. 600-ha large area is used mainly for cultivation, grazing and waste dumping.

In the last decades two environmental projects were carried out, in order to assess all the necessary requirements for the ecological restoration of the drained lake. In the first project the environmental parameters and requirements for the re-flooding of the former Mouria Lake were studied (Georgiadis et al., 1998). In 2005, a multidisciplinary scientific team from the Departments of Geology and Biology of the University of Patras, as well as the Pyrgos Municipal Enterprise for Development was established in order to implement an integrated restoration and rehabilitation plan of the original lake, based on the knowledge and experience that were acquired during the construction and monitoring of a pilot-scale wetland (Chatziapostolou, 2009; Karagianni, 2009; Karapanos, 2009). A 0.5-ha large, pilot-scale wetland was constructed with the purpose to meet both the scientific and the social (aesthetic, recreational, educational, commercial etc.) needs; it is located in the SW part of the drained Mouria Lake (Figure 1b) (Chatziapostolou et al., 2008; Chatziapostolou, 2009; Karagianni, 2009; Karapanos, 2009).

The objective of the present study is to assess the geological and pedological features in the pilot-scale wetland, focusing on the physical properties of the sediments, as well as on their mineralogical and chemical composition. The aim is a better understanding of the factors that controlled the wetland's temporal and spatial evolution, as well as the assessment of the post-drainage anthropogenic impact, emphasizing on the degree of soil degradation.

2. Geological Setting

The Mouria Lake once covered the eastern part of the Neogene Pyrgos Basin, which formed during the post-alpidic extensional phase. The bedrock consists of Palaeocene limestone of the Ionian zone and evaporites (Kamberis, 1987). Neogene alternations of clay, sand and sandstone and conglomerate constitute the northern part of the surrounding area of the original lake (Hageman, 1977; Streif, 1980; Kamberis, 1987) (Figure 1a). According to Streif (1980), the sediments filling the drained Mouria Lake are Holocene alluvial deposits. The eastern, western and northern margins of the drained area consist of Holocene lagoonal sediments, while a sand barrier system and marine deposits constitute the southern margins (Figure 1a). More specifically the drained area is covered by sandy mud and mud, whereas the coastal area consists of sand. Silty sand covers a small part at the southwest and west of the former lake (Chatziapostolou, 2009).

Geomorphologically, the entire area is characterized by a smooth relief. The region is flat at the Mouria Lake area (-2.2 to +2 m altitude) and semi-mountainous at the western, northern and northeastern margins (Figure 1a). The Mouria sub-basin evolution is controlled by the Pyrgos Fault striking W-E at the Mouria Lake area and NNW-SSE at the Agoulinitsa Lake area (Koukouvelas et al., 1996).

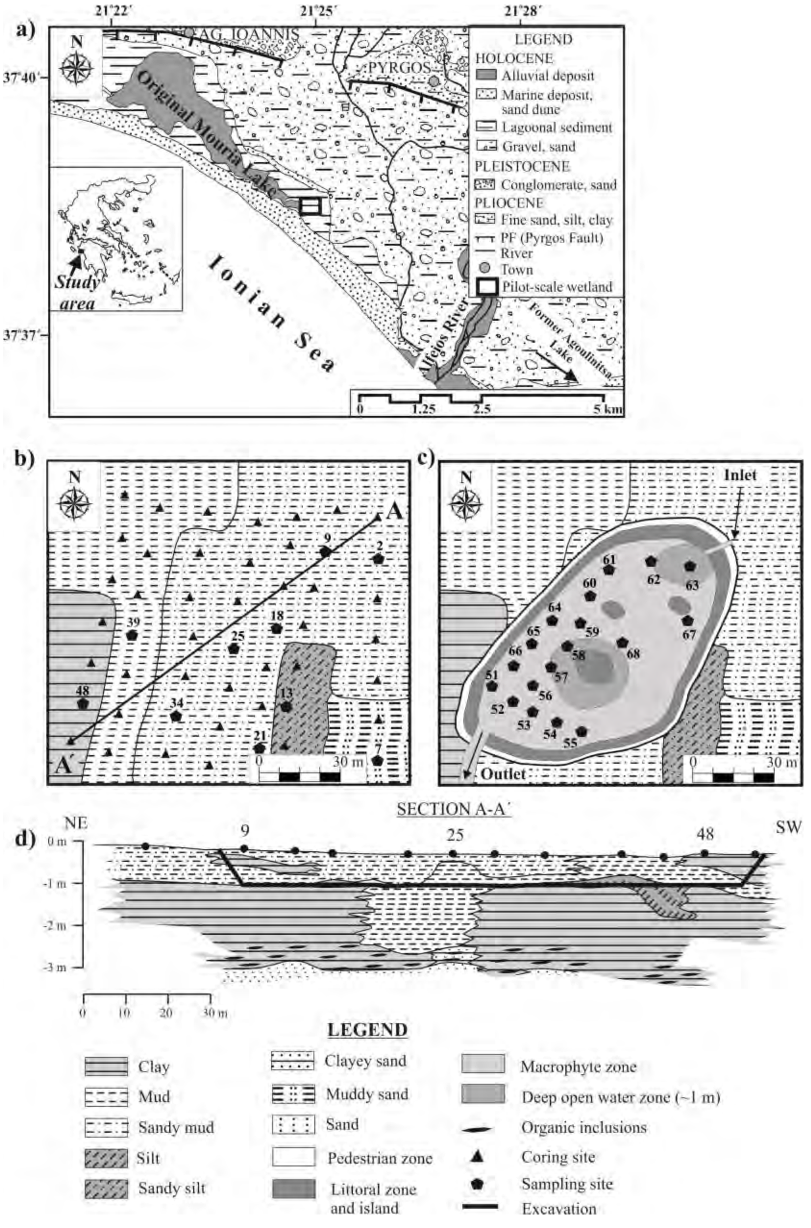

Figure 1 - a) Simplified geological map of the Pyrgos area (after Chatziapostolou et al., 2008), b) Geological map of the pilot-scale wetland before its construction, c) Sketch-map of the pilot-scale wetland and the sampling sites, after re-flooding with rainwater, d) Cross section AA'.

The study area has a typical temperate Mediterranean climate, with cold-wet winters and warm-dry summers. According to data from the Hellenic National Meteorological Service (Karapanos, 2009), during the last 25 years the mean annual precipitation is 828 mm. Mediterranean salt meadows and Thermo-Mediterranean riparian galleries dominate at the drained Mouria Lake, while reed beds (*Phragmites australis*, *Typha domingensis*) develop in the draining channels. Towards the coast an elongate zone with Mediterranean tall humid herb grasslands of the *Molinio-Holoschoenion* alliance occurs besides the embryonic shifting dunes. Sand dune vegetation is mainly composed of *Ammophiletea* species (Chatziapostolou et al., 2008; Karagianni, 2009).

3. Materials and Methods

Detailed geological mapping was conducted at the 0.5-ha large area, where the pilot-scale wetland was constructed (Figure 1b). Twenty-four sediment samples up to 3 m depth (Figure 1b) were collected prior to the construction of the wetland, from four freshly dug pits, using a hand-driven corer. After the construction of the pilot-scale wetland and the re-flooding with rainwater, sixteen sediment samples (Figure 1c) were picked up from the substrate of the lake using a hand-driven corer.

The pH and the electric conductivity values were measured in aqueous solution (1:10 sample/water ratio). Cation exchange capacity was determined according the US EPA 9081 method (Chapman, 1965). Particle size analysis was performed using the pipette method, while the sand fraction was determined after dry sieving (Gee and Bauder, 1986). The samples were classified according to Folk's (1954) classification, while the estimation of statistical grain-size parameters was accomplished using the mathematical formulas of Folk and Ward (1957) and Buller and McManus (1972).

The mineralogical analyses of the samples were carried out using a Bruker D8 Advance X-ray diffractometer equipped with a LynxEye® detector. The scanning area covered the 2θ interval 3-60°, with a scanning angle step of 0.015° and a time step of 0.3 s. Clay minerals were identified on the bulk samples (2θ=3-60°), as well as on the samples after treatment with ethylenoglycole (2θ=3-30°) and after heating at 490°C for 2 h (2θ=3-30°), with a scanning angle step of 0.015° and a time step of 0.1 s (Gee and Bauder, 1986; Moore and Reynolds, 1997). The mineral phases were identified with the use of EVA software and quantified using a Rietveld-based quantification routine with the TOPAS® software.

Total element concentrations were determined in solutions, which were prepared after microwave-assisted acid digestion (US EPA, 1996), applying Flame Atomic Absorption Spectrometry (for Ca, Fe, K, Mg, Na) and Inductively Coupled Plasma – Mass Spectrometry (for As, Co, Cr, Cu, Li, Mn, Ni, Pb and V).

4. Results and Discussion

4.1. Lithological data

Sandy mud and mud cover the greatest part of the study area, except the SW part where clay dominates, and the SE part which consists of sandy silt and muddy sand (Figure 1b). The uppermost horizons of the sediments (up to 1 m depth) overlie 2 m-thick clay. The sand layer (up to 3 m depth) constitutes the substrate of the lagoonal environment representing the dune system that was developed across the coastline (Figure 1d, Chatziapostolou, 2009). This layer hosts a brackish confined aquifer body.

The pilot-scale wetland was constructed (Figure 1c) according to the guidelines of Bendoricchio et al. (2000).

4.2. Laboratory Determinations

The high pH values of all the sediment samples reveal strong alkaline environment (Table 1). The electric conductivity (EC) values are high in surface samples from soil pits and cores revealing high content of dissolved solids (salt). In contrast EC values in samples from the re-flooded with rainwater wetland are lower than those before the construction, because of the dissolution effect of rainwater. The Cation Exchange Capacity (CEC) of the samples from soil pits and cores range from 9.7 to 25.4 meq/100 g and from the re-flooded with rainwater wetland from 17.7 to 23.4 meq/100 g (Table 1).

Table 1 – Physical properties of the sediments.

Physical properties		Sample Site					
		Soil pits				Cores	Re-flooded pilot-scale wetland
		7	13	25	34	2, 9, 18, 21, 39, 48	51-68
pH	Min	9.5	10.1	9.3	9.5	9.3	8.6
	Max	9.7	10.4	9.9	10.3	10.3	9.6
	Average	9.6	10.3	9.6	9.9	9.9	9.3
EC (μS/cm)	Min	568.0	222.0	82.0	601.0	754.0	592.0
	Max	1209.0	916.0	1067.0	836.0	850.0	758.0
	Average	889.0	606.0	472.0	723.0	802.0	675.0
CEC (meq/100 g)	Min	10.2	24.6	13.5	13.1	9.7	17.7
	Max	13.2	25.4	23.3	20.5	16.9	23.4
	Average	11.7	25.0	19.0	17.7	13.7	20.6

The results of particle size analysis of the samples from the soil pits and cores are presented in Figure 2. The statistical grain-size parameters, such as median (Md), mean size (Mz), sorting (σ_I), skewness (Sk_I), kurtosis (K_G) and quartile deviation (Qda), were estimated and plotted on scatter diagrams in order to determine the origin of the sediments and the depositional environments (Figs. 3a-d) (Stewart, 1958; Buller and McManus, 1972; Amaral and Pryor, 1977; Friedman, 1979). According to the scatter diagrams the fine sediments are of fluvial origin and were deposited in quiet water under low energy conditions (lacustrine environment). The sand is of coastal origin revealing high-energy depositional environment (wind and wave interaction) (Figs. 3a-d). According to Kraft et al. (2005) the sand layer belongs to the Agoulintsa barrier system, which was formed during the Early Mycenaean period (1600-1400 B.C.) and underlie the actual barrier system, which started forming during the Classical period (500 B.C.) and is still active.

4.3. Mineralogical Composition

The quantitative determinations of the mineral matter reveal that quartz (7.8-47.7 wt.%), K-feldspars (2.3-18.8 wt.%), plagioclases (2.3-30.0 wt.%), clay minerals such as illite (3.3-69.7 wt.%), chlorite (4.0-10.6 wt.%), vermiculite (0.4-10.0 wt.%) and kaolinite (1.4-10.9 wt.%), and calcite (5.7-58.0 wt.%) are the main mineral phases. Dolomite occurs only in 5 samples and its content ranges from 1.1 to 14.0 wt.%. Halite (0.2-10.1 wt.%) and sylvite (0.2-2.8 wt.%) constitute minor phases.

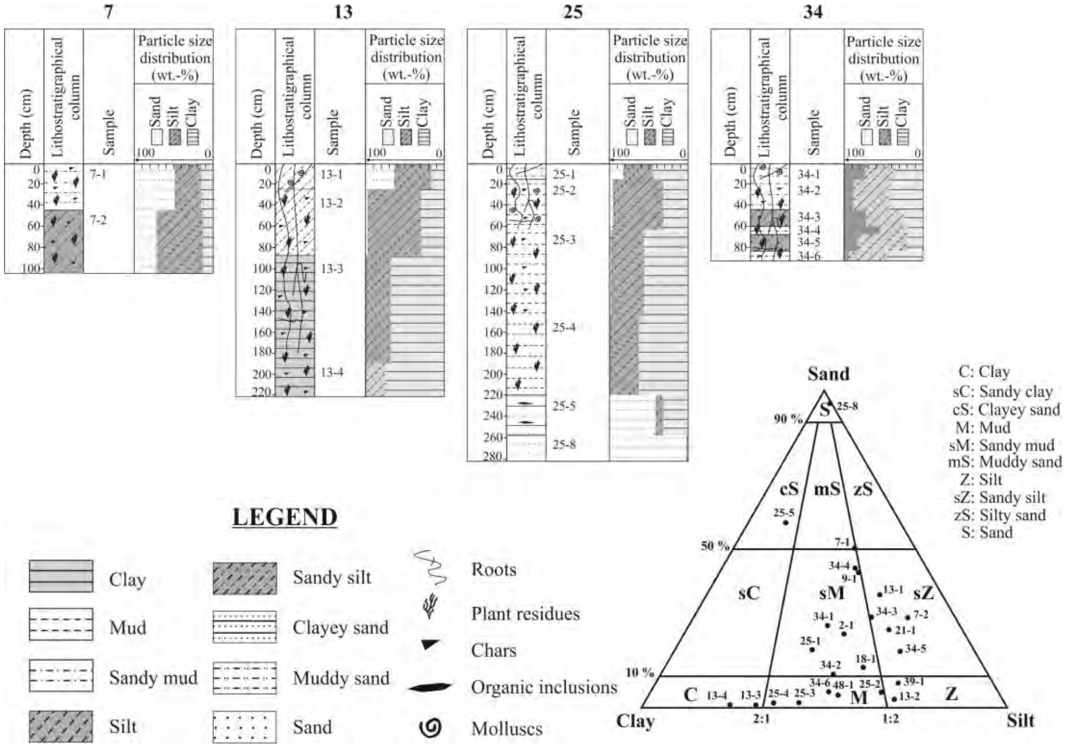

Figure 2 - Detailed lithostratigraphical columns showing the vertical particle size distribution (wt.%) of the soil pits and ternary diagram for the classification of all the samples according to Folk (1954).

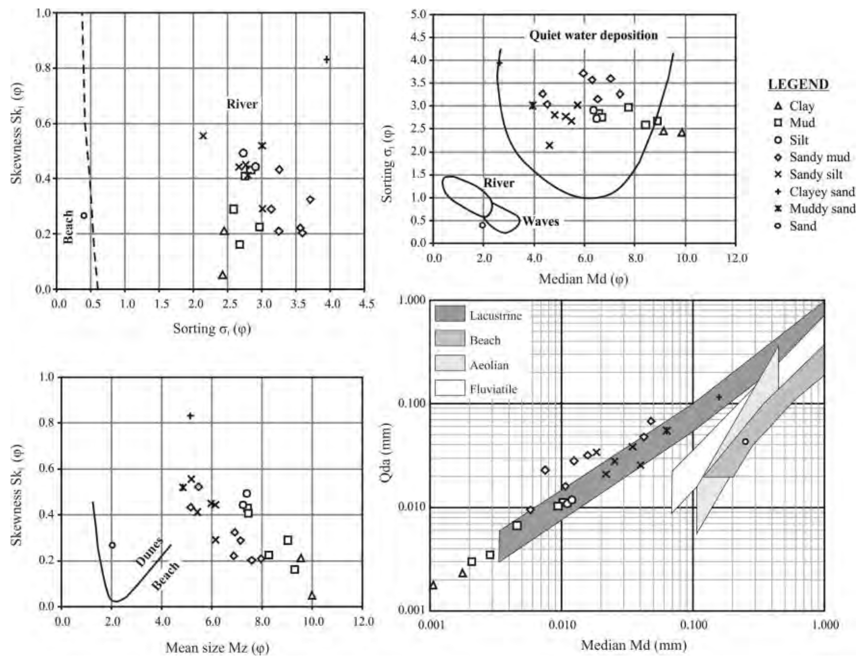

Figure 3 – Scatter diagrams of the statistical particle-size parameters (Stewart, 1958; Buller and McManus, 1972; Amaral and Pryor, 1977; Friedman, 1979) showing the origin of the sediments and the deposition environment.

In the study area, quartz, clay minerals (illite, chlorite) and feldspars are having a clastic origin (Drees et al., 1989; Huang, 1989), deriving from the weathering and erosion of the surrounding Neogene and Quaternary rocks. Vermiculite and kaolinite are formed from the weathering of mica and chlorite and rarely by feldspars alteration (Paquet and Clauer, 1997). Calcite has clastic or authigenic origin (Doner and Lynn, 1989; Paquet and Clauer, 1997) from Ca-rich waters originated from limestone and evaporite dissolution. Dolomite has clastic origin (Paquet and Clauer, 1997). Halite and sylvite may have clastic or authigenic origin (Doner and Lynn, 1989; Paquet and Clauer, 1997) and seems to derive from the sea spray.

4.4. Chemical Composition

The average values of the major element concentrations in the sediments from the soil pits and cores, as well as from the re-flooded with rainwater pilot wetland are presented in Table 2. The high content of the sediments in Ca, compared to the average content in upper crust (Wedepohl, 1995) and in soils and sediments worldwide (Reimann and Caritat, 1998), is due to the significant presence of clastic calcite and feldspars. Additionally, Ca may be contained in the samples as exchangeable cation in clay minerals or as a component in the skeletal remains of molluscs. The average Fe content of the sediments is 3.6 wt.%; iron in soils and sediments is mainly associated with clay minerals, such as vermiculite and chlorite (Dixon and Weed, 1989; Siegel, 2002). Amorphous phases (e.g. iron oxides and hydroxides) or sulphide minerals might be contained in the sediments in low amounts, since they were not detected on the X-ray diffractograms.

Table 2 – Chemical composition of the studied samples (in mg/kg, on dry basis, except otherwise cited.

	Average in soil pits and cores	Average in the re-flooded pilot-scale wetland	Upper crust[1]	Soils and sediments worldwide[2]
Ca (%)	6.8	NA	2.9	1.4
Fe (%)	3.6	NA	3.1	3.5
K (%)	1.5	1.9	2.9	1.4
Mg (%)	0.9	NA	1.4	0.9
Na (%)	1.1	NA	2.6	1.0
As	7	9	2	5
Co	20	28	12	10
Cr	150	178	35	80
Cu	34	51	14	25
Li	35	38	22	20
Mn	916	1044	527	530
Ni	117	164	19	20
Pb	18	21	17	17
V	83	NA	53	90

NA: not analysed, [1]: average concentration in the upper crust, according to Wedepohl, 1995, [2]: average concentration in soils and sediments worldwide, according to Reimann and Caritat, 1998)

The Fe-ions in groundwater of Western Peloponnese (Karapanos, 2009) and the presence of iron-rich minerals in the study area is due to the weathering and erosion of the Upper Jurassic – Low

Cretaceous cherts of the Pindos zone, which constitute the eastern margins of the broad surrounding area (Varnavas and Panagos, 1983; Lambrakis et al., 2004). The significant occurrence of kaolinite and feldspars explains the K content in all the samples. The comparison of the average K content in soil samples to that from the re-flooded pilot wetland shows that K concentration has not changed and is not influenced by the flooding. The Mg in the sediments from the study area is associated with the presence of aluminosilicate minerals and dolomite. The high Na content compared to the average content in the upper crust (Wedepohl, 1995) and in soils and sediments worldwide (Reimann and Caritat, 1998) is due to the presence of feldspars, clays and halite.

The studied samples display medium concentrations in As, Li, Pb and V and high concentrations in Co, Cr, Cu, Mn and Ni, compared to the average contents in soils and sediments worldwide (Reimann and Caritat, 1998). The weathering of the pre-Neogene and Neogene formations of the marginal areas is considered to be the major factor controlling the chemical composition of the sediments, although anthropogenic activities, such as pesticide application and waste dumping, seem to contribute as well. Background element concentrations are needed in order to assess possible contamination. The comparison among the average concentrations of As, Co, Cr, Cu, Li, Mn, Ni, Pb and V in the samples taken from the substrate of the re-flooded new lake, with those of the samples taken before the construction reveal similar variation without any significant differentiation.

5. Concluding Remarks

The fine sediments, which constitute the uppermost horizons (up to 3 m thickness) of the study area have fluvial origin and were deposited under low energy conditions (lacustrine deposition environment). These sediments constitute the lagoonal bottom material, which extents all over the area ever covered by Mouria Lake. The sand layer (up to 3 m depth) constitutes the substrate of the lagoonal environment revealing high energy depositional conditions.

The major factor controlling the chemical composition of the sediments is the weathering of the pre-Neogene and Neogene formations outcropping in the surrounding areas.. Anthropogenic activities, such as the application of pesticides and uncontrolled waste dumping, may contribute as well.

The strong alkaline conditions prevailing in soils and sediments of the study area inhibited trace element mobilization. Continuous monitoring of the variation in chemical composition and physical properties of the sediments in the pilot wetland, is necessary, in order to predict and prevent a possible mobilization of hazardous trace elements and the subsequent release to the environment.

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