GEOLOGICA CARPATHICA, JUNE 2008, 59, 3, 261–268

Application of grain-size trend analysis and spatio-temporal changes of sedimentation, as a tool for lagoon management. Case study: the Kotychi lagoon (western Greece)

PAVLOS AVRAMIDIS[1*], DIONISIOS BOUZOS[1], VASILIOS ANTONIOU[2] and NIKOLAOS KONTOPOULOS[1]

[1]University of Patras, Department of Geology, 26500 Patras, Greece; p.avramidis@upatras.gr
*Present address: Technological Educational Institute of Mesolonghi, Department of Aquaculture and Fisheries Management, 30200 Mesolonghi, Greece; pavramid@teimes.gr
[2]Agricultural University of Athens, Iera Odos 75, Athens, Greece

(Manuscript received June 15, 2007; accepted in revised form December 13, 2007)

Abstract: The Kotychi lagoon is located on the northwest Peloponnese Greece, along a wave dominated and microtidal coast. The lagoon is one of the most important ecological areas in Greece, with international significance as it is protected by the Ramsar International Convention and is listing in the Natura (E.C.) Catalogue. For the present study 59 surficial samples were collected from the bottom of the lagoon, on a grid basis (approximately 300 m spacing) using a grab and were analysed for their grain size distribution as well as grain size parameters, mean, variance and skewness. Using the moment measures, grain-size trend analysis was made and the definition of trend vectors were estimated. Grain-size trend analysis indicates that the sediments of the lagoon are mainly sandy mud. Application of trend analysis indicates that the sediment pathways along the lagoon can be related to a) the sediments source area of the lagoon (small river supplies), b) wind related water circulation and c) the NW and SW wind directions. Moreover, comparing 1990 and 2000 satellite images we have detected three major areas where the shallow waters show a significant increase: area (a) in the northeast part of the lagoon, area (b) in the middle-west part and area (c) in the southern part. All these changes are related to river discharges and to the winnowing effect. Detection of changes in the coastline of the lagoon, showed a total reduction of areas covered by water by up to 13.8 %. The biggest change was detected in the northeast and in the southeast area of the lagoon and is related to the sediment supply from the periphery of the lagoon and to a minor degree to the bottom sediment pathway and winnowing effect. The rate of change of the area covered by water shows a rapid filling up of the lagoon and that additional measures have to applied for the protection of the lagoon ecosystem.

Key words: Greece, Kotychi lagoon, sedimentology, coastline changes, grain-size trend, remote sensing.

Introduction

Sediments are typically described by particle size distribution based on the log of the grain size. Use of the moment measures (mean, variance and skewness) highlights important features which can help in the interpretation of depositional environments and the mean of sediment transport. The use of change of the moment measures demonstrate the transport processes, selective entrainment transport and deposition. Several methods using grain-size parameters of bottom sediments have been proposed (McCave 1978; McLaren 1981; McLaren & Bowles 1985; Gao & Collins 1992; Le Roux 1994; Le Roux et al. 2002). All methods are based on the same premise that sedimentary processes produce changes in the grain-size parameters. McLaren (1981) used the spatial changes in moment measure to identify the transport directions in a modern environment. This author concluded that successive deposits along the transport path must become better sorted and more skewed, although they can be finer or coarser. Later McLaren & Bowels (1985) modified the previous conclusion which relates two cases of grain-size trends to net transport paths. Although this approach is widely accepted, Gao & Collins (1991) reexamined the model and support the view that other cases can also occur along the transport path. Later Gao & Collins (1992) developed a model for the analysis of grain-size trends, which defines transport vectors for a grid of sampling sites and based on this model the significance of the exported trends are statistically tested on the basis of the length of the characteristic vector. This model is supported by Gao (1996) with a FORTRAN program which defines the sediment transport pathways.

All the above methods have been applied mainly in harbours where deposition of silt clay and sand is a problem, and the pattern of sediment movement is the main parameter which has to be evaluated. Moreover, the estimation of sediment transport paths is a tool for the protection and the evolution of wetlands. The pathways in lagoons and lakes and specially in environmentally protected areas, can help in protection and planning administrative strategies for these ecosystems. In the present paper we apply the Gao & Collins (1992) method to the Kotychi lagoon, which is located in western Greece and is one of the main environmentally protected areas in Greece. Remote sensing satellite data were used, as they provide a unique tool for research and monitoring coastal areas and deltaic environments (Ciavola et al. 1999). Additionally, mapping of the coastline using multitemporal satellite data has been proved to be an important tool, as existing maps are often not accurate (in the first place), not updated and so sometimes unable to follow rapid coastline changes.

The objectives of the present paper are the calculation of the surfare sediments distribution pattern, the estimation of sediment transport pathways along the lagoon and the relationship between hydraulic conditions and lagoon siltation. Moreover, the topographical alteration of the lagoon, based on satellite data, during the last ten years is presented and compared with the sediment pathways and their source areas. Modeling the sediment transport pathways and changes around the Kotychi lagoon could be a managerial tool for researchers to propose solutions in these kinds of ecological problems.

Geological setting

Greece has 24 lagoons, with a total surface of 24,500 ha. 10 % of this surface is natural, 85 % partially natural and 5 % man-made. There are also marshes with a total surface of 70,900 ha (Greek Coastal Zone Management Report, 2006). Wetlands are among the most threatened environmental elements. A lot of detrimental impacts have been observed as a result of intensive agriculture, aquaculture, industry, overexploitation of the water resources, pollution due to human activities and urbanization, intense pasturing as well as over-fishing.

The study area is the Kotychi lagoon (Fig. 1a,b), located in the western Peloponnese (Fig. 1a), Greece. It is one of the

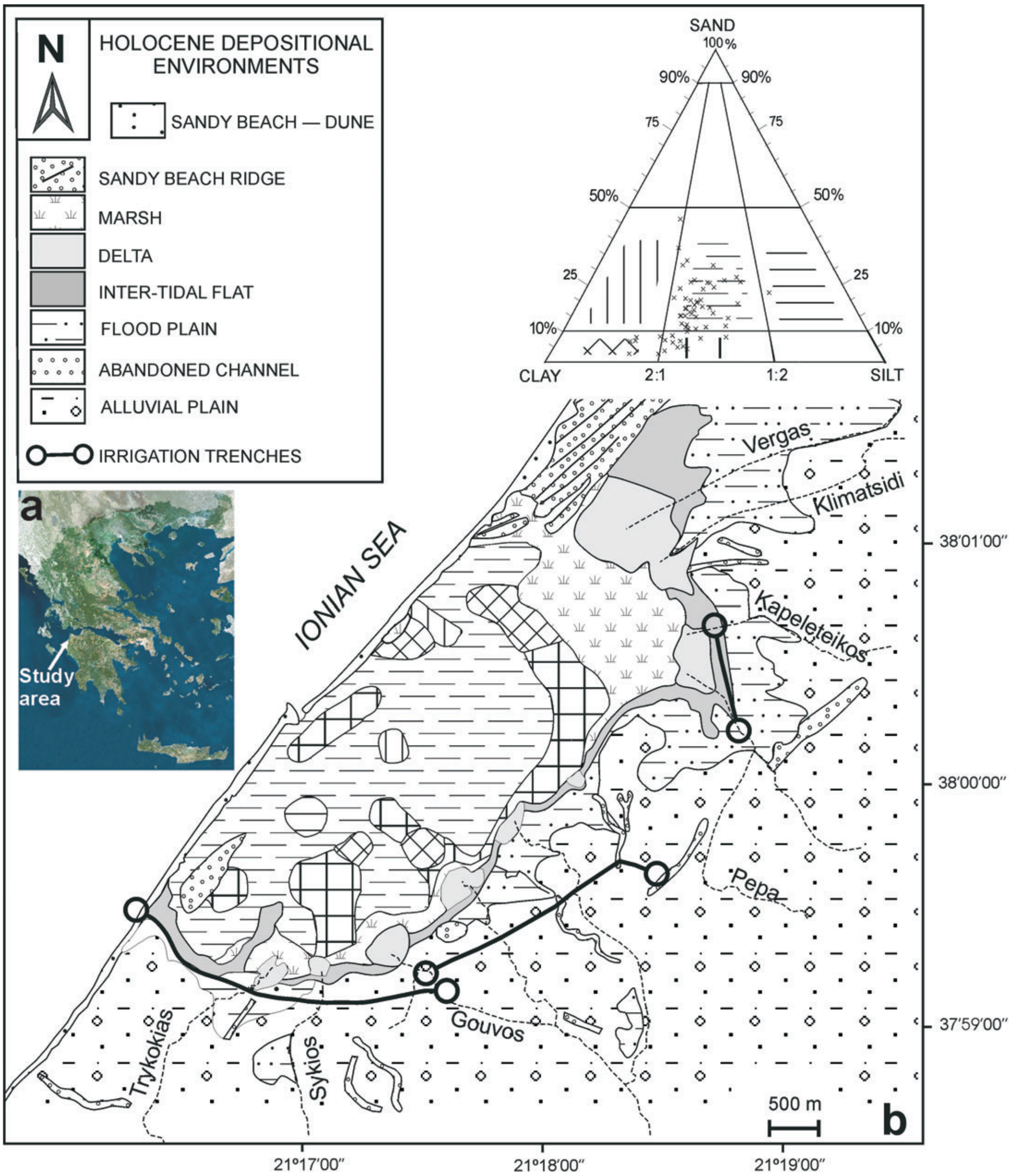

Fig. 1. **a** — Location of the study area and **b** — Geological map of the area around the Kotychi lagoon and lithological type distribution of the bottom lagoon sediments based on Folk's (1974) diagram.

most important ecological areas in Greece, with international significance as it is protected by the Ramsar International Convention and is listing in the Natura 2000 (E.C.) Catalogue with code GR2330006 as a Special Protected Area.

The lagoon is located along a wave dominated and microtidal coast. On the west side it is separated from the open sea by a low relief barrier island, and has limited communication with the open sea, with a stable, short and narrow inlet (Fig. 1a). On the landward lagoonal margins to the east, small scale deltas are prograded into the lagoon. Intertidal and supratidal mud flats are developed among deltas, covered with plants, e.g. Salicornía (Fig. 1b). Depths in lagoon decrease gradually with distance from the landward side of the barrier island to the inner lagoonal margins. Although the maximum depth is 2.5 m in front of the inlet, the average depth is only 0.5 m (Fig. 2a). Four artificial, very shallow channel-like features run at right angles to the barrier coast and one more parallel to the coast. The average surface water temperature ranged from 10 °C during the winter to 27 °C in the summer. The lagoon is affected by semidiurnal tides. The tidal range is of the order of 10–15 cm. The maximum combined tide and meteorological tide amplitude is of the order of 25–30 cm. The tidal current speed is 10–30 cm/sec at the inlet and approximately 0.5–1 cm/sec in the lagoon and is subjected by NW and SW winds (Bouzos & Kontopoulos 1998) (Fig. 2b). Kalivas et al. (2003), using as a reference lagoon area in the year 1945, showed that the water area of the lagoon was permanent decreased between the years 1945 and 1987 (from

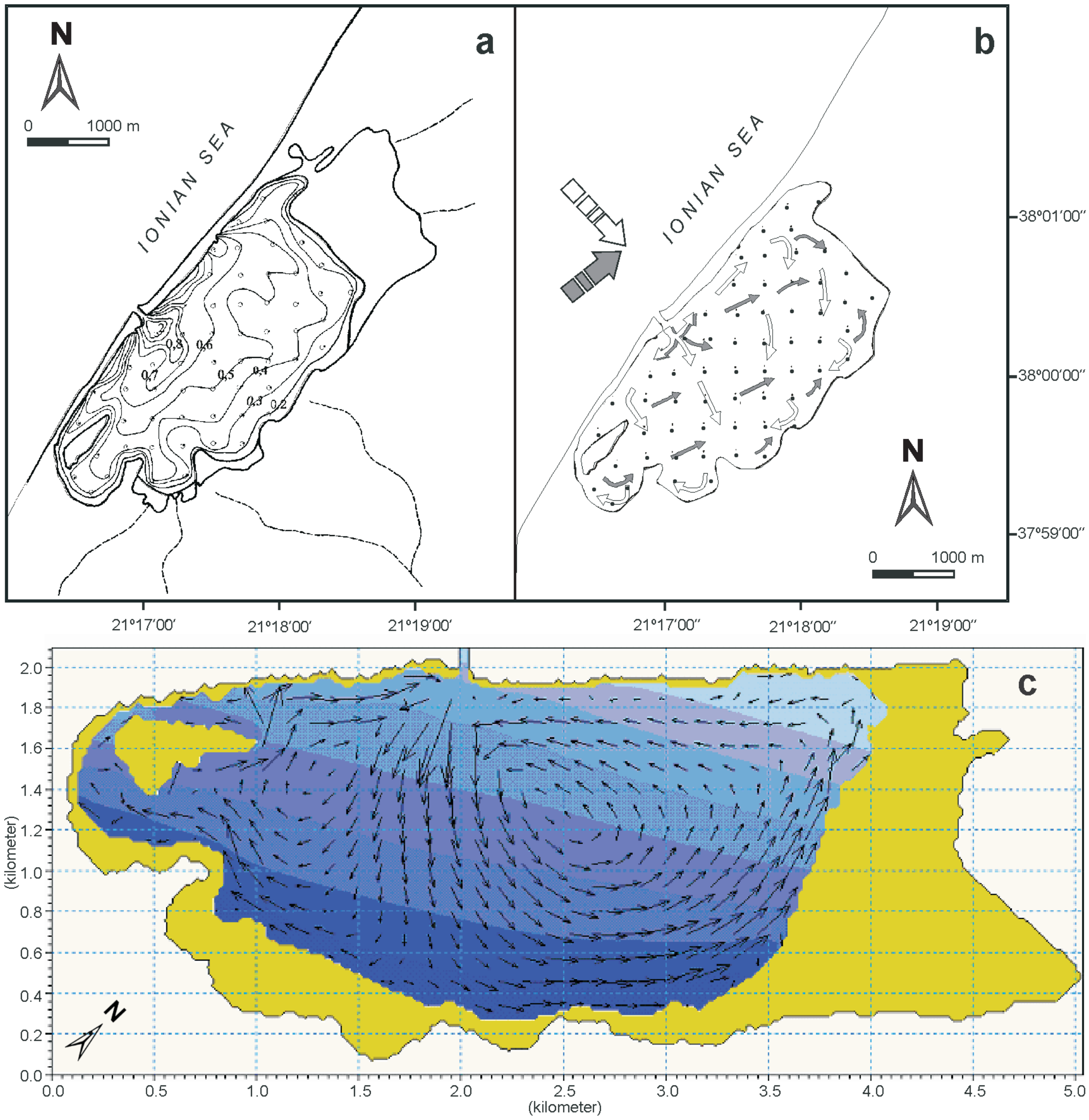

Fig. 2. **a** — Bathymetric map with the location of surface sediment samples; **b** — the development of current trends inside the lagoon under the influence of the main prevailing winds, NW (white arrow) and SW (black arrow) (based on nearest meteorological station of Andravida airport; current trends inside the lagoon were measured using buoy drifter) (Bouzos & Kontopoulos 1998) and **c** — representative hydrodynamic model, simulating water transport, based on a two dimensional model of finite differences (Fakiris 2005).

97.8 to 40.3 % of the lagoon reference area). Moreover, in 1987, the area of the lagoon covered by land or swampy areas reached its maximum (59.7 % of the reference area) (Kalivas et al. 2003). These dramatic developments are due to irrigation works, which began in the early 70's and rapidly changed the ecological and environmental situation of the lagoon (Karantounias et al. 2005). The irrigation trenches which directly influence the lagoon are established in the southern part of the Kotychi watershed. The major source area for the lagoonal sediments is river supply. The main rivers which supply the lagoon with water are the Vergas, Klimatsidi, Kapeleteikos, Pepa, Gouvos, Sykios and Trykokias (Fig. 1b). The biggest flood discharges are from the Vergas (278 m^3/sec) and Trykokias rivers (108 m^3/sec). A minor contribution is shell fragments from autochthonous biogenic production. Aeolian sands, suspended sands eroded on tidal flats and lagoonal margins, or sand washed into the lagoon by washover fans are negligible.

Methods

Sedimentological data

In 1995, 59 surface samples were collected from the bottom of the lagoon (Fig. 2a), on a grid basis (approximately 300 m spacing) using a grab. The grab sampler enables the top 10 cm of sediment to be sampled. Positioning was achieved with a hand held GPS (accuracy 5 m). All the samples were analysed for their grain size distribution. Material coarser than 4 Φ was dry sieved, while fine-grained material >4 Φ was analysed using the pipette method, and grain size distribution was calculated. Grain size parameters (mean, variance and skewness) were calculated. In each sample location, the lagoon depth were measured and a bathymetric map of the lagoon was produced on the basis of 1995 data (Fig. 2a).

The grain-size trend analysis was done, based on Gao & Collins (1992) model, using Type 1 ($\sigma_2<\sigma_1$, $\mu_2>\mu_1$ and $Sk_2<Sk_1$) and Type 2 ($\sigma_2<\sigma_1$, $\mu_2<\mu_1$ and $Sk_2>Sk_1$) trends. The above models apply to inner continental shelf and coastal environments, and seem to be the most appropriate as their patterns have been used in investigations with artificial tracer experiments using hydrodynamic data (Delisle 1994; Turner 1994). The calculations were made with a FORTRAN program developed by Gao (1996) and the definition of trend vectors were estimated.

Satellite data set

In order to estimate the spatio-temporal changes, based on satellite images of the lagoon, the following data sets were used:

i) A Landsat 5 Enhanced Thematic Mapper (ETM+) image (7 spectral bands) was obtained covering the study area (path 184, row 034), acquisition date: 28 August 1990 (5 % cloud cover).

ii) A Landsat 7 Enhanced Thematic Mapper (ETM+) image (7 spectral bands) was obtained covering the study area (path 184, row 034), acquisition date: 15 August 2000 (5 % cloud cover).

iii) Topographical maps scale 1:50,000, from the Hellenic Army Geographical Service.

The following steps describe the various image processing methods and techniques:

Initially, a digital elevation model (DEM) of the study area was extracted from the 1:50,000 scale topographic maps published by the Hellenic Army Geographical Service. The contour lines were digitized with an interval of 20 meters. Additionally, surface-specific point elevations (using bathymetric data from 1995), including high and low points, were digitized in order to improve the final digital product. A linear interpolation method was applied, based on the Bongefors distance method (ILWIS User's Guide, 2003) to transform the contour data into a DEM, with a spatial resolution of 25 meters. With the intention of verifying its fidelity, the digital elevation model was plotted against the 1:50,000 scale contour map, by interpolating the elevation values and overlapped onto the original topographical map. It showed a very good correspondence of the contour lines.

In order to create a False Colour Composite image we have to combine the adequate spectral bands and display them in the RGB colour system. There are 120 possible colour combinations of the data for a large number of applications. Theory and experience, however, show that a small number of colour combinations are suitable for most applications. The optimum band combination is determined by the terrain, climate and nature of the interpretation project (Sabins 1997). In the present study the selected bands are 1, 2, 3 forming the false colour composite image 3, 2, 1 (RGB) for detecting shallow areas of the lagoon, and 4, 5, 7 forming the false colour composite image 7, 5, 4 (RGB). After constructing the 4 composite images (2 for each scene), the ERDAS Imagine software program was used to detect any changes in the shallow waters and coastline. The final products of the above procedure were two images pointing out the total changes between the two scenes.

Results

Grain size distribution — Trend vectors

The main physical geographical characteristics of the area around the Kotychi lagoon are presented in Fig. 1b as well as the geological map of the area and the distribution of lithological types of the lagoon surface sediments. The lithological types were estimated according to Folk's (1954) classification. The main lithological type of the lagoon sediments is sandy mud, with exceptions in the eastern edge of the lagoon and some locations around the lagoon where thinner material of silt-clay has been deposited. The sand class is almost absent from the lagoon sediments and is restricted only to a narrow zone on the sea side. The mean grain size of the Kotychi lagoon sediments ranges from 5.15 Φ to 9.9 Φ with an average of 7.38 (Table 1). The distribution of mean size shows three small regions that are covered by finer sediments (Fig. 3a). These are: 1) the area close to the marsh environment, 2) the zone in front of the Gouvos river mouth, and 3) the part of the lagoon just behind the northeastern part of the barrier island (Fig. 1). The rest of the lagoon is characterized by coarser ma-

Table 1: Particle size analysis results and the moment measures for the analysed samples.

SAMPLE	LOCATION UTM		MOMENT MEASURES					PARTICLE SIZE %		
	E	N	Md	Mz	σ1	SK1	KG	SAND	SILT	CLAY
1	4209707.3	261708.5	8.8	9.1	2.81	0.11	0.84	2.76	33.58	63.66
2	4210037.8	262011.1	9.6	9.7	3.30	–0.16	1.12	7.17	23.18	69.65
3	4210336.9	262337.1	8.0	7.8	4.41	–0.17	1.15	16.65	32.98	50.37
4	4210614.4	262345.2	10.0	9.9	2.67	–0.09	0.82	1.80	23.70	74.50
5	4210884.7	262597.2	9.9	9.8	3.07	–0.18	1.17	5.86	21.95	72.19
6	4211090.0	262969.4	7.9	7.3	2.41	–0.28	1.44	10.48	41.89	47.63
7	4211081.5	263262.0	6.8	7.0	3.80	0.01	1.39	18.21	47.36	34.43
16	4210843.2	262962.2	8.4	7.9	1.82	–0.50	3.13	6.07	23.38	70.55
17	4210605.1	262662.3	8.1	7.3	4.63	–0.33	1.53	20.09	27.70	52.20
18	4210327.7	262654.2	7.4	5.2	4.99	–0.54	0.94	30.75	24.95	44.31
19	4210027.9	262352.6	8.2	7.9	3.08	–0.19	1.68	9.04	37.07	53.89
20	4209689.5	262318.3	7.1	5.4	4.67	–0.53	1.44	25.78	39.66	34.56
21	4209681.0	262611.1	7.0	5.3	4.70	–0.49	1.06	36.38	20.92	42.70
22	4209681.0	262611.1	7.3	5.4	3.81	–0.73	1.14	25.07	35.06	39.86
23	4209989.3	262620.0	7.7	6.2	3.95	–0.56	1.93	18.84	35.17	45.99
24	4210319.2	262947.0	7.7	6.8	3.00	–0.35	1.42	17.73	34.88	47.39
25	4210627.5	262955.9	8.0	7.0	3.39	–0.55	2.08	14.85	35.53	49.63
26	4210616.2	263346.2	8.8	9.0	3.15	–0.01	0.96	6.27	31.96	61.77
33	4210218.3	263237.0	8.0	8.4	3.16	0.11	0.91	6.83	42.13	51.05
34	4209980.1	262937.1	7.9	7.7	3.87	–0.19	1.54	13.87	37.32	48.81
35	4209671.8	262928.2	8.0	6.9	3.12	–0.54	1.68	15.41	34.65	49.94
36	4209403.6	262603.0	7.6	6.6	3.60	–0.39	1.74	17.21	37.49	45.30
37	4209412.1	262310.2	7.4	6.5	5.13	–0.23	0.87	25.19	30.11	44.70
39	4209422.0	261968.7	8.1	7.1	2.89	–0.53	1.82	14.26	32.71	53.04
40	4209399.7	261675.1	7.3	5.5	4.29	–0.49	0.82	32.25	25.51	42.24
41	4209376.0	261430.2	8.0	7.9	4.33	–0.16	1.08	16.52	32.80	50.69
42	4209111.4	260983.0	7.2	6.0	3.01	–0.58	0.91	25.30	44.59	30.11
43	4209162.4	261350.7	7.8	6.4	3.05	–0.64	1.29	19.35	35.97	44.69
44	4209030.5	261639.9	7.1	5.3	3.87	–0.60	1.58	21.77	54.84	23.39
45	4209082.9	261958.8	8.1	7.3	2.64	–0.57	1.77	9.93	39.18	50.90
46	4209072.9	262300.4	8.2	7.6	2.20	–0.34	1.59	5.96	36.63	57.41
47	4209064.4	262593.2	8.0	7.3	4.67	–0.24	1.07	19.84	31.22	48.94
48	4209394.4	262920.1	7.1	5.4	3.88	–0.56	0.98	26.79	42.69	30.52
49	4209385.9	263212.9	8.1	7.4	2.37	–0.47	1.54	10.45	35.91	53.64
50	4209663.3	263220.9	7.8	7.5	4.31	–0.14	1.04	19.24	32.98	47.77
51	4209971.6	263229.8	8.1	7.3	2.67	–0.43	1.70	11.63	34.18	54.19
52	4210087.2	263501.8	8.2	8.2	3.91	–0.11	1.07	14.20	33.94	51.86
53	4210078.0	263818.9	7.6	8.1	3.03	0.17	1.05	7.22	49.39	43.39
59	4209778.9	263492.8	8.3	8.5	3.76	–0.08	1.10	10.01	36.95	53.04
60	4209470.6	263483.9	8.5	8.8	2.94	0.12	0.84	4.24	38.32	57.44
61	4208992.9	262932.8	6.5	5.9	5.20	–0.18	0.95	30.71	33.91	35.38
62	4208777.0	262926.6	7.7	7.3	4.25	–0.22	1.47	18.49	35.20	46.31
63	4208787.0	262585.1	8.2	8.2	2.45	0.05	1.52	3.92	36.84	59.24
64	4208796.2	262267.9	8.2	8.5	3.67	–0.03	0.95	11.31	35.87	52.81
65	4208806.8	261902.0	8.8	9.0	3.27	–0.04	1.01	7.40	30.00	62.60
66	4208815.4	261609.1	7.0	6.1	5.30	–0.23	1.12	24.96	35.77	39.27
67	4208734.3	261216.1	7.4	6.2	3.72	–0.39	1.30	22.92	34.86	42.22
68	4208776.6	260826.7	7.3	6.1	3.40	–0.43	1.03	25.91	30.81	43.28
69	4208223.8	260737.2	7.9	7.8	4.40	–0.15	1.12	16.06	35.53	48.40
70	4208063.2	260952.3	7.3	7.8	3.42	0.14	0.89	10.89	47.48	41.63
71	4208213.1	261103.2	7.5	6.7	3.37	–0.35	1.57	16.86	39.79	43.36
72	4208462.6	261012.9	8.2	7.5	2.30	–0.46	1.70	7.76	33.41	58.84
73	4208545.7	261332.7	7.9	6.8	5.26	–0.30	0.99	23.15	28.00	48.85
74	4208537.9	261601.1	9.0	9.0	3.16	–0.03	0.80	5.46	34.65	59.89
75	4208528.0	261942.6	9.4	9.3	2.87	–0.03	0.72	1.77	32.30	65.93
76	4208518.0	262284.2	8.3	8.3	4.18	–0.16	1.13	14.14	32.54	53.32
77	4208450.7	262477.6	7.4	7.0	3.37	–0.23	1.62	15.10	41.65	43.25
78	4208191.7	261835.2	8.5	8.8	2.90	0.13	0.81	3.40	39.89	56.71
79	4208137.2	261589.4	6.9	7.5	3.55	0.18	0.91	13.46	46.92	39.62

terials (Fig. 3a). This pattern of the distribution of mean size does not relate to the water depth; thus wave energy cannot significantly distribute sediment according to grain size.

The sorting fluctuates between 1.81 Φ and 5.30 Φ with an average of 3.57 Φ (Table 1). The sediments are very poorly sorted to extremely poorly sorted (Fig. 3b). This indicates that the lagoon sediments were not transported for a considerable time or distance. The skewness varies from –0.64 to 0.17 with an average of –0.26 (Table 1). The major part of the lagoon is covered with coarse to very coarse skewed sediments (Fig. 3c). The near symmetrical and fine skewed sediments constitute only 27 % of the lagoon and occur mostly in the

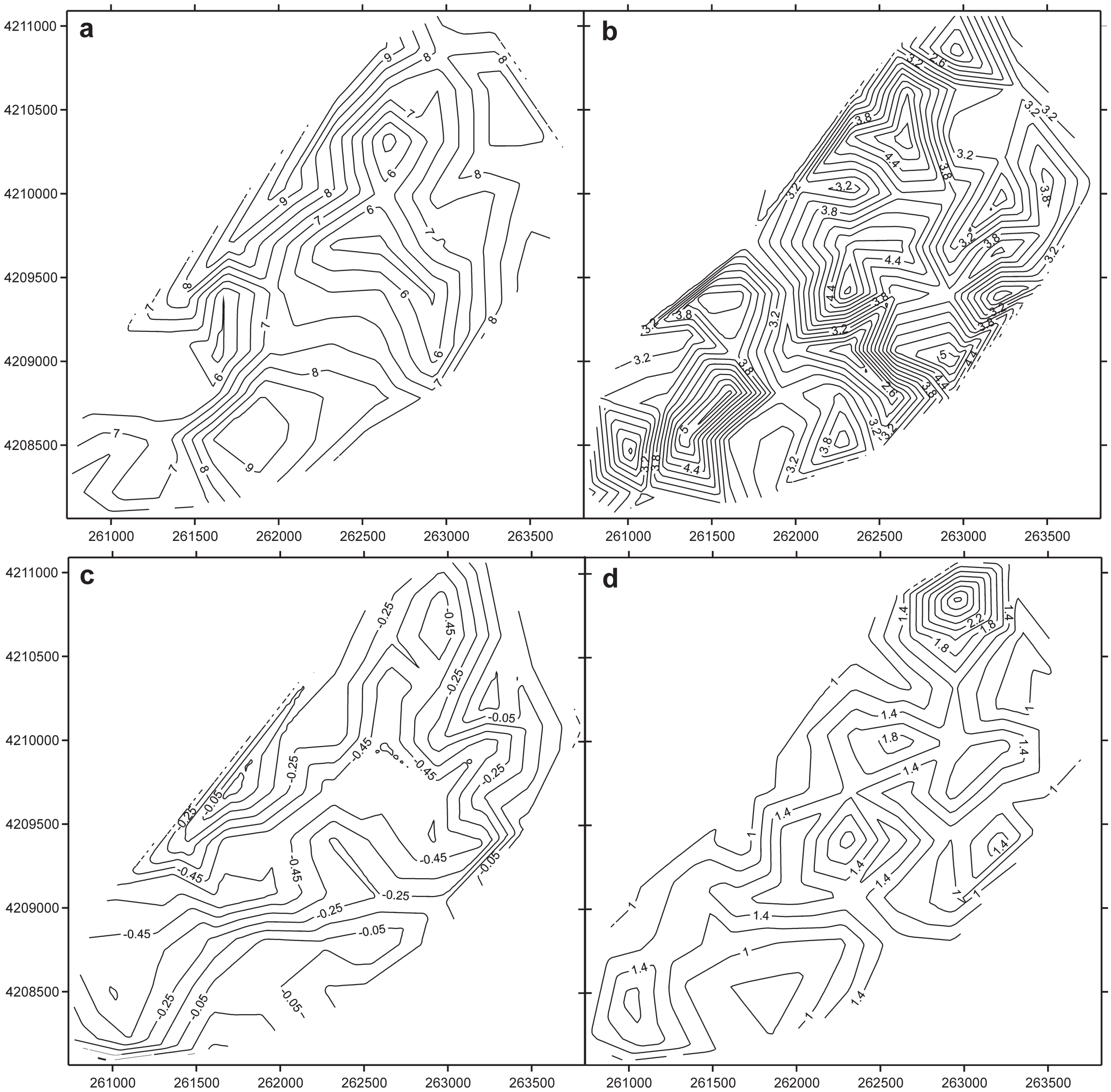

Fig. 3. Distributions of: **a** — graphic mean size (Mz), **b** — graphic standard deviation (σ), **c** — skewness (Sk) and **d** — kurtosis (Kg).

first two mentioned regions (the area close to the marsh environment and the zone in front of the Gouvos river mouth), (Fig. 3c). The dominance of the negatively skewed sediments suggests that they are unaffected by the current action. Furthermore the negative sign of skewness shows the operation of the winnowing action and the absence of deposition (Duane 1964). On the contrary, the two regions (the area close to the marsh environment and the zone in front of the Gouvos river mouth) indicate deposition or a state of flux (Fig. 3) (Duane 1964).

The kurtosis varies from 0.72 to 3.13 with an average of 1.27 (Table 1). The major part of the lagoon is covered with mesokurtic to very leptokurtic sediments (Fig. 3d). The platykurtic sediments constitute only 15 % of the lagoon. The mesokurtic to leptokurtic nature of sediments refers to the continuous addition of finer or coarser materials after the winnowing action and retention of their original characters during deposition.

Interpreting the results of the grain-size trend analysis (Fig. 4) we cannot recognize a dominated unidirectional trend. We observed two probable trends, a) NW and b) NE that could be related to the main wind directions and to the river supplies. The small depth of the lagoon can explain the close relation between the dominant winds and the sediment transport paths. As coarse material seems to be absent, the source material of the river seems to be fine-grained and does not differentiate the grain-size distribution of the lagoon sediments. Furthermore, the pattern of the transport paths illustrates a subtle cyclic circulation (Fig. 4). It is probable that the wind plays a dominant role in this circulation of the lagoon as a result of the fact that the lagoon has a small size and is very shallow. On the basis of data from the nearest meteorological station of Andravida airport and using a buoy drifter, Bouzos & Kontopoulos (1998) suggest that the NW winds drive the water to the SE and introduce a counter-clockwise circulation while the SW winds cause an anti-counter-clockwise (Fig. 2b). In order to simulate the water transport and set up a reliable hydrodynamic model, using the two dimensional model in finite differences program, Mike21 (DHI), Fakiris

Fig. 4. The identified residual grain-size trend pattern, consisting of transport vectors, for Kotychi lagoon, obtained from the Gao (1995) FORTRAN program. After exporting the vector data from the FORTRAN program, the plot was produced by SURFER.

(2005) also suggests that the wind currents produce a two cell of cyclonic circulation with an opposite direction to each other (Fig. 2c). For the above interpretation he took into account the bathymetry of the lagoon, the bottom friction coefficient and the prevailing winds. So, this circulation should be considered the main mechanism for the winnowing effect.

Spatio-temporal changes

After constructing the 4 composite images (2 for each scene) (Fig. 5), we detected three major areas where the shallow waters show a significant increase from 1990 to 2000: area (a) in the northeast part of the lagoon, area (b) in the middle-west part and area (c) in the southern part (Fig. 6a).

We have also detected two areas with a small decrease of shallow waters: one in the middle-east area of the lagoon (d) and another one in the northwest (e) (Fig. 6a).

Detection of changes in the coastline of the lagoon showed that we have a total reduction of areas covered by water estimated at 13.8 % (Fig. 6b). The total water surface in 1990 was up to 5,800,000 m^2 while in 2000 the water surface had decreased up to 800,000 m^2. The greatest changes were detected in the northeast and in the southeast area of the lagoon. The above results are similar to those of Kalivas et al. (2003). Kali-

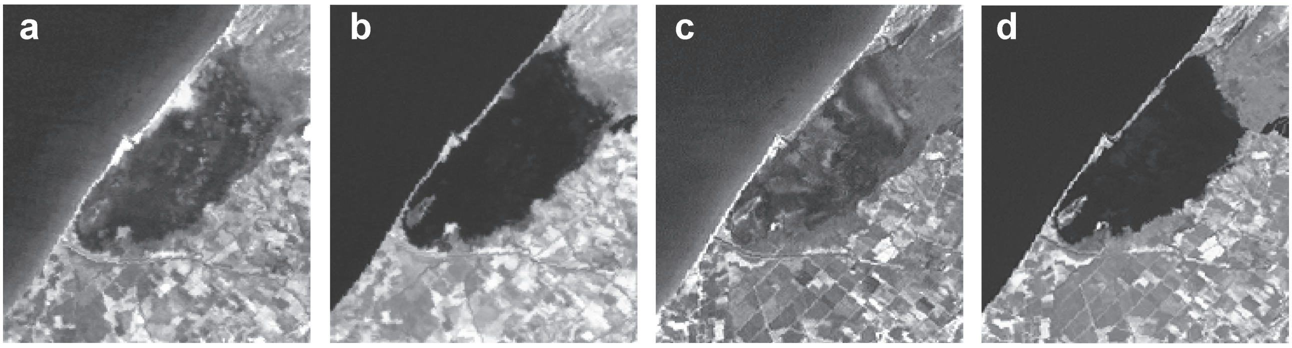

Fig. 5. The four false colour scenes of 1990 and 2000, we used for change detection. **a** — Bands 3, 2, 1, of 1990; **b** — Bands 7, 5, 4, of 1990; **c** — Bands 3, 2, 1, of 2000, and **d** — Bands 7, 5, 4, of 2000.

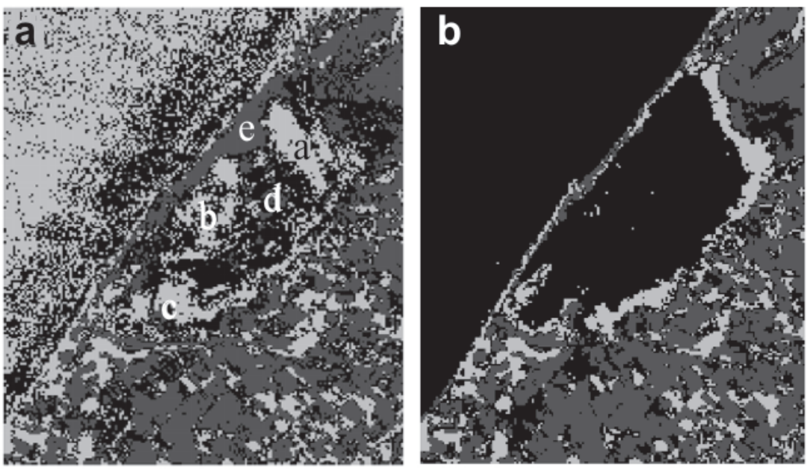

Fig. 6. Change detection **a** — of shallow areas and **b** — of coastline in the lagoon. Bright colours show an increase of the property, dark colours a decrease and black shows that no changes were detected.

vas et al. (2003) using as a reference area the lagoon surface in the year 1945, showed that the water surface of the lagoon was permanent decreased between the years 1945 and 1987 (from 97.8 to 40.3 % of the lagoon reference area). This dramatic development of the lagoon seems to be constant up to 2000 and is a result of all man's activities as deforestation and agriculture, rapidly changing the ecological and environmental situation of the lagoon.

Conclusion

On the basis of the grain-size distribution, of the bottom lagoon sediments, and the sedimentological environments distribution around the Kotychi lagoon, we can infer that the main source area of the lagoon sediments is the river supplies and a minor contribution is shell fragments from autochthonous biogenic production. Aeolian sands, suspended sands eroded on tidal flats or sand washed into the lagoon by washover fans are negligible. Interpreting the results of the grain-size trend analysis it seems that the sediment transport pathways are related to the contemporary effect of prevailing waves — winds and river discharges. The spatio-temporal changes of the lagoon water depth from 1990 to 2000 suggest three main sites of deposition/siltation and a reduction of areas covered by water up to 13 % (800,000 m^2). Moreover the lagoon area has the greatest reduction in the northeast and southeast parts of the landward margin. All these changes appear to be regulated of the winnowing action of the water circulation and are related to the river discharges.

The same regulating factors also operate for the distribution of sediments. The water circulation is the product of the action of the NW and NE winds and probably has a cyclonic character. In order to avoid the silting up of the lagoon, disposal of debris must be prohibited, particularly in the northeast and southeast parts of the landward margin. If not, the landward margin of the lagoon will be moved seawards from these two parts. Moreover, all human activities such as deforestation and agriculture, influenced the sediment accumulation pattern.

References

Bouzos D. & Kontopoulos N. 1998: Recent sedimentation in the lagoons of western Greece. Example of the Kotychi lagoon. *Bull. Geol. Soc. Greece*, XXXII/2, 237–245.

Ciavola P., Mantovani F., Simeoni U. & Tessari U. 1999: Relation between river dynamics and coastal changes in Albania: an assessment integrating satellite imagery with historical data. *Int. J. Remote Sensing* 20, 3, 561–584.

Delisle T.R. 1994: Sediment movement in the littoral zone at Long Beach, Plymouth Massachusetts. *Unpubl. Masters Thesis*, Boston College, 1–220.

Duane D.B. 1964: Significance of skewness in recent sediments, western Pamlico Sound, North Carolina. *J. Sed. Petrology* 34, 864–874.

Fakiris E. 2005: Study and mathematical simulation of the hydrodynamic and thermosalinity attributes of Kotychi lagoon, West Peloponnese, Greece. *Unpubl. Master Thesis*, University of Patras, Greece, 1–127.

Folk R.I. 1974: Petrology of sedimentary rocks. *Hamphill, Austin,* Texas, 1–182.

Gao S. 1996: A fortran program for grain-size trend analysis to define net sediment transport pathways. *Comput. & Geosc.* 22, 4, 449–452.

Gao S. & Collins M. 1991: A critique of the McLaren method for defining sediment transport paths: discussion. *J. Sed. Petrology* 61, 143–146.

Gao S. & Collins M. 1992: Net sediment transport patterns inferred from grain-size trends, based upon definition of transport vectors. *Sed. Geol.* 80, 1–2, 47–60.

Greek Coastal Zone Management Report 2006: Ministry of environment, physical planning and public works. 1–92.

ILWIS 3.0 for windows User's Guide, 2001. ILWIS Dept. ITC.

Kalivas D.P., Kollias V.J. & Karantounias G. 2003: A GIS for the assessment of the spatio-temporal changes of the Kotychi Lagoon, Western Peloponnese, Greece. *Water Resources Management* 17, 1, 19–36.

Karantounias G.A., Dercas N. & Papazoglou E.G. 2005: Environmental impacts on protected biotopes from irrigation water over consumption and relevant rehabilitation works — the case of Kotychi sea-lagoon. *Proceedings of the 9th International Conference on Environmental Science and Technology*, Rhodes Island, Greece, 1–3 September.

Le Roux J.P. 1994: An alternative approach to the identification of net sediment transport paths based upon grain-size trends. *Sed. Geol.* 94, 1–2, 97–107.

Le Roux J.P., O'Brien R.D., Rios F. & Cisternas M. 2002: Analysis of sediment transport paths using grain-size parameters. *Comput. & Geosc.* 28, 717–721.

McCave I.N. 1978: Grain size trends and transport along beaches: an example from eastern England. *Mar. Geol.* 28, 43–51.

McLaren P. 1981: A interpretation of trends in grain-size measurements. *J. Sed. Petrology* 51, 611–624.

McLaren P. & Bowles D. 1985: The effects of sediment transport on grain-size distributions. *J. Sed. Petrology* 55, 457–470.

Sabins F.F. 1997: Remote sensing: principles and interpretation. *W.H. Freeman and Company*, New York, 1–494.

Turner D.D. 1994: Sediment transport on an estuarine beach: a comparison of different methods. *Unpubl. Master Thesis, Dept. Oceanography*, Univ. Southampton, 1–120.