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MONITORING OF COASTLINE CHANGES USING MULTITEMPORAL SATELLITE DATA: THE CASE OF MESSOLOGI LAGOON SYSTEM AND ACHELOOS-EVINOS DELTAS (W. GREECE)

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ABSTRACT

The broader area of Messologi ecosystem located along the southern coast of Etoloakarnania prefecture, is of great ecological interest. Through time, the area has suffered important changes due to anthropogenic interventions that have partly altered the initial natural parameters. The aim of this paper was the multitemporal monitoring of the coastline changes in the area of Messologi lagoon and the estuaries of Acheloos and Evinos during the span of 1984-1999, using Landsat TM and ETM data. Two different techniques were used in order to detect the probable changes, the band ratioing technique and the Principal Component Analysis. Zones of accretion and erosion were recognized and the two techniques were evaluated.

KEY WORDS: Remote sensing, multitemporal data, coastline changes, erosion, accretion, Band ratioing, PCA, Messologi ecosystems.

1. INTRODUCTION

Coastal zones are areas of major economic and social importance worldwide. In these zones there is intense, diverse activity with consequential environmental impact from fishing, fish farming, industry of all types, release of sewage, pollution by trace metals and organic compounds, eutrophication by terrestrial fertilizers and tourism (Cracknell 1999, Doerffer et al. 1999). Very dynamic coastlines, such as delta and lagoon coast, pose considerable hazards to human use and development, and rapid, replicable techniques are required to update coastline maps of these areas.

Large area remote sensing from satellites provides a unique tool for environmental research and monitoring of coastal areas and deltaic environments (Pramanik et al. 1987, Ciavola et al. 1999, Yang et al. 1999). Moreover, in many parts of the world, the mapping of the coastline using multitemporal satellite data is an important task because existing maps are often not accurate and updated; this is either because the area was only poorly mapped in the first place or because the coastline has been changing (Frihy et al. 1994, Ulbricht & Heckendorff 1998, White & El Asmar 1999).

The study area is a very sensitive and ecologically unstable ecosystem protected by the Ramsar Convention, and composes a hospitality and propagation area for many kinds of the animal kingdom (Karathanasi et al. 1997). The whole area shows complex aspects, both in its morphology and in its environmental dynamic processes.

Through time, the area of lagoon has suffered important changes due to anthropogenic interventions that have partly altered the initial natural parameters, such as sedimentation, flora, fauna, etc. The anthropogenic impact on the lagoon is due to the urban expansion mainly of Messologi and Etoliko towns, the salt industry, the kind and extension of crops (intensive cultivation), the fisheries of the lagoon and the animal production facilities on the surrounding lands (Parcharidis et al. 1999). As a result of the above-mentioned activities and interventions, changes are observed on the chemistry of the lagoon water and the land/sea distribution (erosion and deposition of the sediments). These changes affect dramatically the existing natural biotopes, reducing their extension and inducing a further decrease in the stability of this environment (Bonazountas et al. 1993).

The above reasons provoked the demarcation of this specific study area, investigating the potential offered by the satellite data for the observation and detection of the anthropogenic and natural changes, and simultaneously examining these changes in an ecologically sensitive area.

The aim of this paper was the multitemporal monitoring of the coastline changes in the broader area of

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Messologi lagoon and the estuaries of Acheloos and Evinos, during the span of 1984-1999, using Landsat TM data. The combined study and the appropriate processing of the satellite images have accentuated the natural and anthropogenic changes occurring during the last 15 years. Finally, the followed methodology in the present study could be characterized as a useful tool for environmental planning and management.

2. DESCRIPTION OF THE STUDY AREA

The study area is located at the southwestern extremity of mainland Greece and specifically in the SW part of Etoloakarnania prefecture (Fig. 1). It composes of the Messologi, Etoliko and Klisova lagoons, the estuaries of Acheloos and Evinos, the old lake Meliti and the Platigialio bay. The climate is temperate while the mean annual precipitation, in the area of Etoliko-Messologi lagoons, reaches 786mm.

The area is composed mainly by Ioanian zone rocks and at a lesser extent of Olonos-Pindos and Gavrovo zones (Fleury 1977, Doutsos et al. 1987), such as Pre-Alpine Triassic breccias to the west, alpine Paleocene-Eocene limestone and Oligocene flysch to the east. The post-alpine formations consist of Pliocene sediments located mainly in the semi-mountainous areas, and of Quaternary formations in the lowlands (Kouris & Tsaila-Monopoli 1989, Mettos et al. 1991, Kouris et al. 1996).

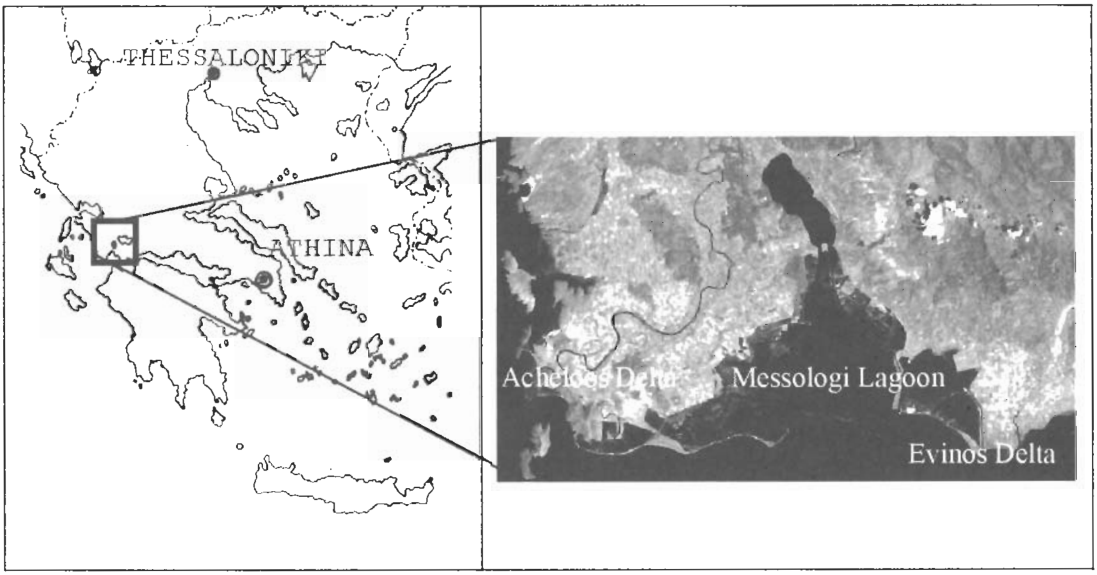

Figure 1. Location of the study area

The genesis of the broader of the lagoons is due to normal faults, with NNW-SSE general direction, that followed the tectonic compression in the beginning of Quaternary (Vasilakis 1998). Thus, the plain and multi-farious coastal area was filled with the fluvial sediments of Acheloos and Evinos rivers, after the creation of grabens, during Miocene and Pliocene periods (Psilovikos 1993). Moreover, these sediments were carried by the coastal currents and created the sandy islets, which compose a peculiar and very significant landform in the outer part of the lagoons (Leontaris 1970). The Acheloos estuary present form as well as the accretion action relate with the recent period of its paleogeographical evolution. This action contributed to the fast exposition of the land during the last Holocene period.

The Messologi lagoon has a maximum length of 27 km and a maximum width of 15 km. It is divided from Patraikos gulf with a series of sandbars, of 80cm height, being extended in almost 12 km length, upon which the facilities of fish farming have been constructed (Karathanasi et al. 1997). These sandy islets cover a variable area, proportionally to the seasons, playing a significant role of a physical breakwater and protecting the shallow lagoon from the erosive action of the waves, provoked by the dominated SE winds. The maximum depth of Messologi lagoon reaches 1.8-2.0 m while the mean depth reaches 80 cm. On the contrary, Etoliko lagoon is deeper with maximum depth 30 m. These two lagoons communicate through the shallow Etoliko straight, in some places the depth reaches 30 cm, a fact that impedes the water circulation between them (Bonazountas et al. 1993).

The plain area dominates, with few exceptions such as Arakinthos mountain (910m.) and some other hills dispersed in the area, and is occupied mostly by crops such as maize, cotton, rice and tobacco.

The Messologi-Etoliko lagoon area has decreased to 150 km^2 due to the reclamation of its lands attributed for agriculture and the salt-industry. The various works such as dams, flood controls, irrigation and drainage works, etc., form a clear anthropogenic environment with many changes, the more serious of which are the coastal erosion, the sea intrusion in Acheloos-Evinos deltas and the cease of land expansion (Marinos et al. 1994, Psilovikos 1994).

Evinos river has formed a remarkable delta with intermittent inundated mudflats composing a significant feeding area for hundred kinds of birds that migrate or/and hibernate. It must be stressed that this fluvial ecosystem will change after the operation of Ag. Georgios dam. On the other hand, the fluvial ecosystem of Acheloos has downgraded considerably because the river flow is under human control, the riparian vegetation has deforested in a great extent and today is restricted along the river banks while the amount of the carried load of sediments has decreased significantly, due to the dams construction along its river bed and the utility of water for irrigation purposes.

The river estuaries provoked, in the past, strong currents flowing parallel to the islets direction. This phenomenon had as a result their continuous supply and reinforcement with new sediments. Today, the substantial decrease of the water flow, due to the diversion of the two rivers, has induced the reduction of the current strength resulting in the wave erosion of the islets.

3. ENVIRONMENTAL VULNERABILITY OF THE STUDY AREA

Environmental vulnerability is the potential for attributes of a system to be damaged and/or destabilized mainly due to exogenous impacts. It is a crucial parameter in sensitive environments such as the study area.

A significant number of risks could affect the broader area of Messologi. These are the following:

a) Meteo events (draughts, floods)
b) Geological events (coastal processes)
c) Anthropogenic events (pollution, solid wastes, urbanization, etc.)

4. DATA AND THEIR PROCESSING

Essentially, change detection involves the ability to quantify temporal effects using multitemporal data sets. It is one of the major applications of remotely sensed data obtained from Earth Orbiting Satellites because of the repetitive coverage at short intervals and consistent image quality (Singh 1989, Frihy et al. 1998).

The main objective of this study is to determine whether relatively short-term (of the order of 15 years) coastline changes can be detected with relatively coarse spatial resolution (30m pixel size) satellite data. Landsat TM and ETM data were acquired covering the study area (path 184 row 033) for two dates (26/7/84 of Landsat 5, and 28/7/99 of Landsat 7). The geometric correction was based on the EGSA87 georeference system by selecting a set of 35 ground control points for each image, mainly along or near the shoreline, and a polynomial transformation of third order. The nearest neighbor resampling method has been used to create the output images with 30 m ground resolution. The root mean squares errors for the rectified and registered images were 0.66 and 0.38, respectively. The ERDAS v. 8.3.1 and ILWIS 2.23 software have been used for the image processing of the satellite image.

Two different techniques were used in order to detect the probable coastline changes:

a) The band ratioing technique (Cracknell and Hayes 1991, Sabins 1997). Ratioing is considered to be a relatively rapid means of identifying areas of change (Howarth and Wickmore 1981, El Raey et al. 1999). The same band of 1984 divided band 7 of 1999 image. Then, the ratio image was converted to log ratio scale for better presentation and interpretation (Fig. 2).
b) The Principal Component Analysis.

The principal components transformation is a statistic technique of many variables, which chooses non-correlated linear compositions (eigenvectors) of variables in such a way that each output principal component (linear composition) shows the minimum variance (Mather, 1991). These variables in the multispectral images are related to the spectral response of various surficial characteristics. One of the important features of PCA is that it produces totally uncorrelated images, thereby removing redundancy in the original data sets (Eklundh and Singh 1993, El Raey et al. 1999).

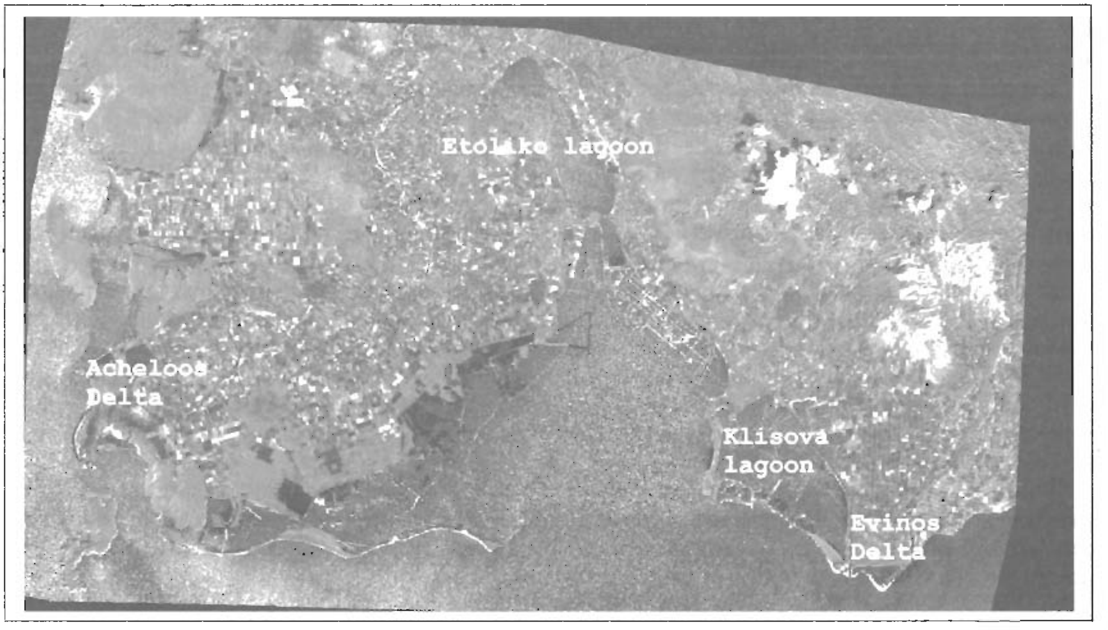

Figure 2. Image of the ratio ETM7_99/TM7_84.

In this study standardized PC transformations were carried out using 6 bands for each date (6 visible and reflected infrared bands). The analysis of eigenvalues and eigenvectors (Table 1) has revealed significant changes, in the broader coastal area of Messologi, along the coastline.

The first principal components, PC1 and PC2, do not show any changes, and PC4 to PC12 do not display features of significance. On the contrary, PC3 is the difference image between the two dates (Fig. 3), resulting from the negative load for all bands of the first date (1984) and the positive load for almost all bands of the second date (1999) with an exception for the negative contribution of TM4-99 which is very close to zero (Table 1).

The PC3 is found to be highly representative not only of the erosion and the accretion of the coastline but also to the construction or the removal of the human facilities, like the fisheries facilities, the new port, etc.

5. ANALYSIS OF THE PROCESSED DATA – CONCLUSIONS

In the two produced images, PC3 and ratio ETM7/TM7, the light gray-white areas designate accretion or some human interventions-constructions that did not exist in 1984 (urban areas, fisheries facilities, salt lakes, etc.) and the dark gray-black areas designate erosion or the removal of the human constructions.

The most significant changes resulting from the interpretation of the two images (Fig. 2, 3) are the following:

- Evinos estuary shows considerable changes, along the coastline, that are related to the erosion of the sediments and their transport and deposition to an adjacent place. The phenomenon of the erosion (black color) and accretion (white color) is due to the simultaneous action of the sea currents and the decreased river supply of sediments loads (Fig. 4).
- In Klisova lagoon the observed changes are related mainly with the removal of the human constructions (black color) (Fig. 4). Furthermore, the deposition of sediments in the outer side of Louros islet (west of Evinos estuary) is obvious (white color) and it seems to have a close relation with the above-mentioned sea currents action.
- In Messologi town significant changes along the coastline have not been observed, with an exception of the west part of it, where a small expansion has occurred (white color) (Fig. 3, point 1).
- Concerning the salt lakes among Messologi and Etoliko towns, there are some small changes related exclusively to the human interventions (new constructions-white color) and the seasonal situation of the salt lakes (the different spectral signatures are due to the unlike seasonal conditions, although the two images were acquired in the same period) (Fig. 3, point 2).

Table 1.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12
TM1_84	0,166	-0,311	**-0,334**	-0,268	0,327	-0,541	-0,166	-0,082	0,275	-0,391	0,125	-0,118
TM2_84	0,246	-0,197	**-0,334**	-0,191	-0,081	0,062	-0,361	0,111	0,158	0,582	-0,136	0,465
TM3_84	0,272	-0,242	**-0,334**	0,031	-0,132	0,360	-0,304	-0,224	-0,574	-0,146	0,054	-0,334
TM4_84	0,320	0,527	**-0,104**	-0,257	-0,587	-0,389	0,006	0,103	-0,108	-0,071	-0,098	-0,101
TM5_84	0,380	0,076	**-0,228**	0,359	-0,083	0,022	0,430	-0,496	0,206	0,086	0,384	0,185
TM7_84	0,326	-0,125	**-0,288**	0,323	0,127	0,066	0,402	0,608	0,015	-0,082	-0,342	-0,122
TM1_99	0,170	-0,304	**0,260**	-0,387	0,144	-0,240	0,482	-0,175	-0,480	0,211	-0,166	0,132
TM2_99	0,247	-0,177	**0,248**	-0,364	-0,124	0,279	0,117	0,096	0,413	0,254	0,221	-0,560
TM3_99	0,263	-0,246	**0,318**	-0,125	-0,293	0,297	-0,024	-0,007	0,183	-0,575	-0,149	0,439
TM4_99	0,301	0,551	**-0,013**	-0,325	0,581	0,329	-0,033	0,061	-0,079	-0,106	0,111	0,140
TM5_99	0,365	0,096	**0,349**	0,318	0,201	-0,142	-0,292	-0,346	0,143	0,115	-0,539	-0,211
TM7_99	0,320	-0,098	**0,408**	0,295	0,045	-0,256	-0,265	0,376	-0,232	0,066	0,536	0,103
% Variance	74,46	14,60	6,67	2,16	0,77	0,55	0,42	0,12	0,08	0,08	0,04	0,04
Eigenvalue	36463	7150,0	3265,0	1059,0	379,0	269,0	207,5	58,2	40,1	37,5	20,9	17,6

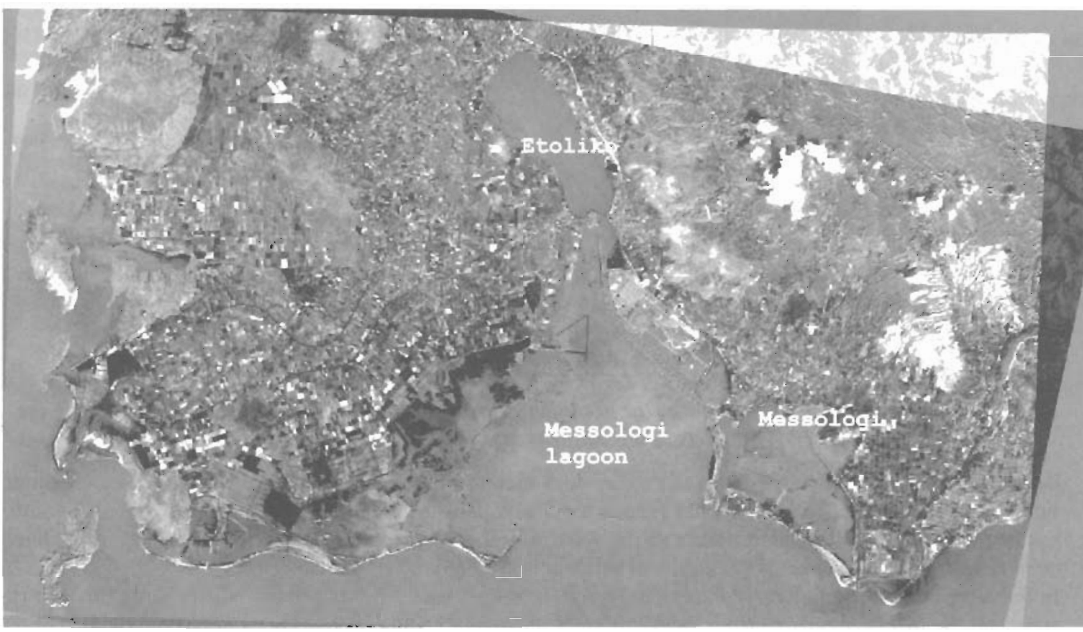

Figure 3. The Principal Component image 3.

- In the broader area of Etoliko town and its lagoon small changes have been observed along the coastline. The expansion of the urban shell is obvious mostly to the south and to the east of the town (white color). As far as it concerns the lagoon coastline there is no evident change. On the contrary, the new national road Antirrio-Ioannina is easily detected. Also, the removal of some constructions (black color - Fig. 3, point 3) is discriminated to the SSE of Etoliko.
- In the Messologi lagoon, there is a significant change in the existent situation of the salt lakes and the fisheries facilities, mostly in the northern-western part, where exposure of the seawater has been observed in extended areas (black col[illegible] southern border of the

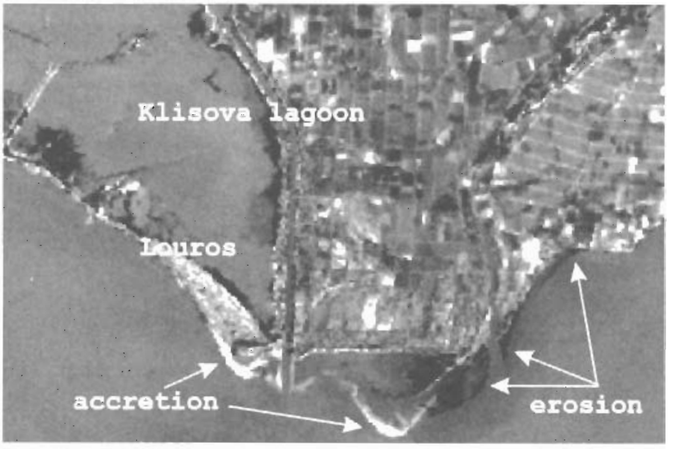

Figure 4. Subscene of PC3 image, representing the Evinos Delta. With black color the erosion and with white the accretion along the coast.

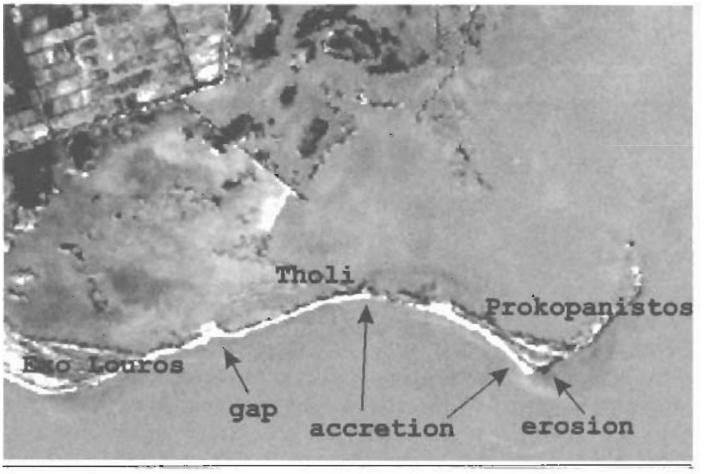

Figure 5. Subscene of PC3 image showing the accretion (white color) and the erosion (black color) along the islets in the southern Messologi lagoon.

lagoon (Exo Louros, Tholi, Prokopanistos), a width increase (accretion) has been detected in their outer side; the most characteristic and intense change is of Prokopanistos islet where a small part of it, to the south, has been eroded and deposited beside to the west. Moreover, some existed gaps between the islets, have been filled with new sediments (naturally or artificially) (Fig. 5).

- In the old estuary of Acheloos (Paliopotamos) some changes have been observed, mostly along the islet (it separates the fish farming area from Patraikos gulf) where new sediments have been deposited (white color) while in some other places the seawater covers the land (black color - Fig. 3, point 6). As regards to the present estuary of Acheloos, there is a significant differentiation that is not totally identified and detected from both techniques. The reduced river supply of carrying load of sediments has provoked some changes in the land distribution in the outlet of Acheloos estuary (Fig. 3, point 7). In the outer side of the land zone, to the west of the estuary, the coastline erosion is obvious (black color - Fig. 3, point 8). The small islands located exactly in the outlet of the estuary have changed in shape and distribution.
- Finally, the new port constructed in the last decade, without being yet in operational use, has significantly changed the coastline in Platigialio bay (Fig. 3, point 9).

The analysis and interpretation of the two different technique products shows spectral similarities. Although in some specific areas the two techniques complement each other, PCA technique seems to detect more clearly and accurately the coastline changes that occurred in the broader area of Messologi lagoon.

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