A SPATIAL ANALYSIS OF AEGEAN SEA USING REMOTELY SENSED IMAGERY AND GIS TECHNOLOGY

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The Aegean is a semi-closed sea that has unique geographical features and bears equal strategic, economic and political importance for two states, Turkey and Greece. These cardinal facts necessitate the establishment and maintenance of a delicate balance between the interests of the two countries in the Aegean Sea. The length of the coastline belongs two countries has been evaluated using different cartographic projections. The water area of Aegean Sea has also been computed. All digitised data was transformed into an equal-area projection surface. On this surface, the total water area of the sea was computed. Finally, true length and area values have been obtained. All this vector data was imported into UTM projection and AutoCAD MAP 2000 environment in order to have a base map data in different projections for GIS applications.

1. INTRODUCTION

Determining the baseline and the maritime line around the Aegean Sea between Greece and Turkey has been a juridical problem for years. The line, from which the outer limits of the State's territorial sea are measured, have been discussed and interpreted for years between those countries. In this study, the Aegean Coastline has been digitised from the satellite imagery covered this area. Because remotely sensed multispectral data collected from satellites provide a systematic, synoptic ability to assess conditions over large areas on a regular basis. Geometric reprocessing of the Landsat MSS images was performed using ERDAS Imagine 8.2 software. All images were geometrically corrected by using 1:50 000 scale topographic maps. Rectified images have been used to create image mosaic. The results, which can be used as reliable criteria for juridical discussions, are presented.

2. DESCRIPTION OF THE STUDY AREA

Study area is limited with the coastal lines of the mainland belong to two countries. Especially at the southern region of the study area continuity of natural coastline cannot be realised. In order to calculate a closed area for Aegean basin connection lines has been used between extremities of the islands, which are shown in Figure 1.

The Aegean Sea is defined according to following geographic locations:

- On the west and north

From Cape Ay Marinas, the southeastern extremity of Peloponnisos, northward and eastward, along the Coast of Greece, to the mouth of Meric River, the frontier between Greece and Turkey.

- On the east

  From the mouth of Meric River southward, along the coast of Turkey to Mehmetcik Cape, joining across the western entrance of the Dardanelles to Kumkale Cape (the common limit with the Sea of Marmara), and then from Kumkale Cape southward, along the western coast of Turkey to Karaagac Bay.

- On the South

  A line joining Karaagac Bay on the southwestern coast of Turkey (this point lies on the boundary between the Turkish geographic regions, the Aegean Region and the Mediterranean Region) southward to Zonari Cape, the northern extremity of Rhodes Island, Greece;

  From Zonari Cape southwestward along the western coast of Rhodes to Cape Prassonisi, southwestward to south extremity of Pigadya Bay of Karpatos Island,

  Southwestward through this island to Cape Kastello,

  Southwestward to the southeast extremity of Crete Island, near Nisi Kavalli Rock, Southwestward along the southern coast of Crete Island to Cape Lendos, the southwest extremity of this island, from there northwestward to Cape Kapiello of the Kithira Island, northwestward along the western coast of this island to Cape Spati, from there to Cape Ay Marinas (Goksel *et al*. 1999).

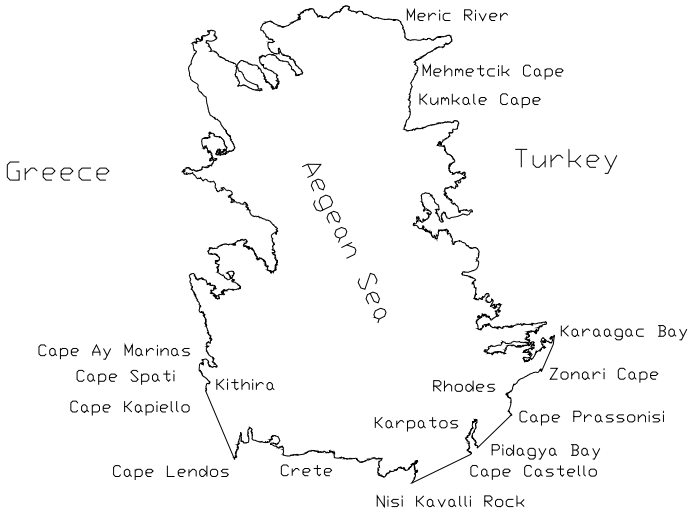

Figure 1. The boundaries of Aegean Sea

3. DATA ACQUISITION AND PROCESSING

The satellite images used here are Landsat-MSS Images, with 80m spatial resolution. The Aegean Sea is covered spatially by 17 Landsat MSS images and all imagery belong to date July and September 1993. Other data sources are the 1: 50 000 scale topographic maps. The area includes approximately 115 map sheets. In this study 91 of them are used for selecting ground control points. Totally 279 ground control points are selected on the 1:50 000 scale maps and they used for the rectification map to image. Approximately 100 control points are also used for image to image rectification. So it can be said that approximately 20 control points was used for each frame. First order polynomial rectification method and nearest-neighbour resampling method are used in this process. A total root mean square (RMS) error between 0.35 and 0.55 pixels is reached for each of the images (Goksel *et al.* 1999).

The 1:50 000 scale topographic maps, which are used for the rectification of images, are produced in the UTM projection system. The mosaicked image of the Aegean Sea is attached as a raster file in to the AutoCAD Map environment. The coastal lines of the mainland and islands are digitised on screen as polylines. Six layers for classification of the lines are generated as described in Table 1. The digitised vector data are represented in Figure 2.

Figure 2. Digitised data

Table 1. Name and description of the layers

Layer	**Description**
COAST_TURK	Coastal line of Turkey
ISLAND_GREEK	Islands belong to Greece
ISLAND_TURK	Islands belong to Turkey
COAST_GREEK	Coastal line of Greece
CONNECTION_LINE	The southern extremity of Aegean basin in water region
ISLAND_GREEK_MIX	The northern coastal lines of the Greek islands on the southern part of the Aegean Sea

4. ANALYSIS

In the UTM coordinate system the earth between latitudes 84°N and 80°S is divided into 60 zones each 6° wide in longitude. Zones are numbered from 1 to 60 proceeding east from the 180th meridian from Greenwich (Snyder 1982). According to this definitions Aegean Sea takes place in the zones with number 34 and 35. The central meridians of these zones are λ_o=21° and λ_o=27° respectively. The coordinates of ground control points that lie in UTM zone 34 are transformed to the UTM zone 35.

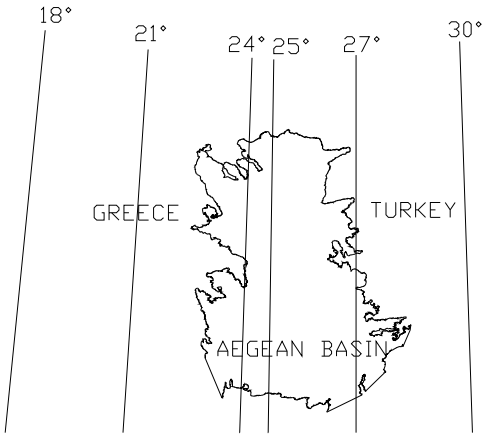

Figure 3. The meridian interval covers Aegean Basin

The digitised coordinates are the UTM coordinates according to the central meridian λ_o=27° East. The ellipsoidal longitudes and latitudes are then computed from these UTM plane coordinates using inverse solution. The UTM coordinates are computed according to the central meridians λ_o=21° and λ_o=25°. The length of the geodesic for each segment between the consecutive points is calculated using the ellipsoidal coordinates. For the complete algorithms for such computations the interested readers may consult Maling 1992, Pearson 1990 and Leick 1995 or other texts of geodesy and cartography.

4.1. Distance Comparison

In UTM system distortions increase away from the central meridian. The effect of such distortions causes wrong comments during discussions about the length of the coastal lines. Turkey is approximately 200km far away from the 21°meridian. Greece is approximately 275km far away from the 27° meridian. Because of these reasons calculations made in two zones 35 and 34 respectively. The lengths of the lines for each layer are computed for those two zones and compared with the lengths of geodesic. As a suggestion non-standard central meridian is chosen as 25° which goes through the middle of the study area. The calculations are repeated for this central meridian. The results are presented in Table 2. The differences of the lengths from the true lengths of geodesic are also presented in Table 3.

Table 2: The lengths computed from UTM coordinates using different central meridian (m)

Layer	**Length of Geodesic**	**λ_o=21° (ZONE 34)**	**λ_o=25° (non-standard)**	**λ_o=27° (ZONE 35)**
COAST_TURK	2328640.455	2336191.443	2328832.937	2327807.118
ISLAND_GREEK	6792776.086	6803017.685	6791117.209	6792962.766
ISLAND_TURK	470182.299	471460.468	470147.977	470018.038
COAST_GREEK	2729884.068	2730438.442	2729492.849	2732040.255
CONNECTION_LINE	328529.493	329335.863	328561.787	328573.026
ISLAND_GREEK_MIX	948645.503	950425.984	948517.200	948719.539
AEGEAN BASIN	6335699.507	6346391.719	6335404.761	6337139.938

Table 3: The differences from the length of geodesic (m)

Layer	**λ_o=21°**	**λ_o=25°**	**λ_o=27°**
COAST_TURK	7550.988	192.482	-833.337
ISLAND_GREEK	10241.599	-1658.877	186.68
ISLAND_TURK	1278.169	-34.322	-164.261
COAST_GREEK	554.374	-391.219	2156.187
CONNECTION_LINE	806.370	32.294	43.533
ISLAND_GREEK_MIX	1780.481	-128.303	74.036
AEGEAN BASIN	10692.212	-294.746	1440.431

During distance calculations with the UTM coordinates it is suggested that if the distance reduction adds to the coordinates the computed distance has closed to the distance on the ellipsoid (Leick 1995). Therefore all of the calculations are repeated using these reductions for each central meridian mentioned above. The results are presented in Table 4. The differences of the lengths computed with reductions are also compared with the lengths of geodesic and the results are presented in Table 5.

Table 4: The lengths computed from UTM coordinates with distance reduction

Layer	**Length of Geodesic (m)**	**λ_o=21° (ZONE 34)**	**λ_o=25° (non-standard)**	**λ_o=27° (ZONE 35)**
COAST_TURK	2328640.455	2328173.628	2328200.100	2328201.213
ISLAND_GREEK	6792776.086	6791455.370	6791476.050	6791477.599
ISLAND_TURK	470182.299	470089.892	470093.855	470093.971
COAST_GREEK	2729884.068	2729383.322	2729378.051	2729370.655
CONNECTION_LINE	328529.493	328445.532	328449.064	328450.114
ISLAND_GREEK_MIX	948645.503	948457.287	948459.723	948461.388
AEGEAN BASIN	6335699.507	6334459.757	6334486.926	6334483.371

Table 5: The differences from the length of geodesic

Layer	**λ_o=21°**	**λ_o=25°**	**λ_o=27°**
COAST_TURK	-466.827	-440.355	-439.242
ISLAND_GREEK	-1320.716	-1300.036	-1298.487
ISLAND_TURK	-92.407	-88.444	-88.328
COAST_GREEK	-500.746	-506.017	-513.413
CONNECTION_LINE	-83.961	-80.429	-79.379
ISLAND_GREEK_MIX	-188.216	-185.780	-184.115
AEGEAN BASIN	-1239.750	-1212.581	-1216.136

4.2. Area Comparison

During juridical discussions on the water area liability between countries, the main problem is often the comparison of the areas of islands and their percentage to the total water area. Therefore method which is used for the area calculations is very important and critical.

UTM system is based on the ellipsoidal transverse Mercator projection, which has a cylindrical and conformal feature. On conform projections the areas are not preserved cause of the area deformations and therefore it is not suitable for area comparison. In order to analyse the distortions of the area values obtained from the UTM coordinates, it is decided to calculate an area on an equal-area projection. The Lambert azimuthal equal-area projection is selected for this purpose. The plane coordinates are computed for this projection using ellipsoidal longitude and latitude values obtained from the inverse solution (Snyder 1982). The area values for the total Aegean basin are calculated using UTM coordinates with central meridians 21°, 25° and 27° respectively and using the Lambert equal-area projection coordinates. The results are presented in Table 6. The differences of the areas from the area computed from the equal-area projection coordinates are shown in Table 7.

Table 6: The Aegean water area (m^2)

Area computed from the Lambert equal-area projection coordinates	206964497861.30
Area computed from UTM coordinates (λ_o=21°)	207555013567.24
Area computed from UTM coordinates (λ_o=25°)	206964837384.42
Area computed from UTM coordinates (λ_o=27°)	206990657707.94

Table 7. The area comparison of the Aegean water area (m^2)

	(λ_o=21°)	(λ_o=25°)	(λ_o=27°)
Difference (m^2)	-590515705.90	-339523.12	-26159846.64

The centre point for the Aegean Sea is calculated as φ_o=38°17′27″ and λ_o=25°04′49″. The area reduction values are also computed using these coordinates according to the central meridians 21°, 25° and 27° respectively by using Gaussian radius of curvature as 6373.363km for the central latitude (Maling 1992). The differences from the true area are also compared with the area reduction values and the results are shown in Table 8.

Table 8. Comparison of the differences with the area reductions

	(λ_o=21°)	(λ_o=25°)	(λ_o=27°)
Area Reduction (km^2)	-649.041	-0.251	-143.618
Difference (km^2)	-590.516	-0.340	-26.160

5. CONCLUSION

On juridical discussions for determining the baseline between Turkey and Greece in the Aegean sea it is suggested that it will be more reasonable to study with the UTM coordinates computed for a non-standard central meridian such as 25° which goes through the middle of the Aegean region. By calculating distances or the lengths of coastlines the distance reduction bring to sufficient results. It is also suggested that it is necessary to select an equal area projection for area calculations. If this is not possible, in that case it is highly recommended that to add the area reduction values to the areas obtained from the UTM coordinates.

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