Estimation of the Coastline Changes Using LIDAR

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In recent years, sustainable development has been a very popular subject. Sustainable development allows economic growth, social welfare and environmental protection to enhance each other. The management of environmental resources in accordance with the principles of sustainable development has become crucial in many areas including coastal resources. Integrated Coastal Zone Management is one of the tools to achieve this goal. Coastal zones involve many different elements of development and interaction and these elements change due to natural or human factors. Temporal change in coastal zones is reflected on the coast line. Coast line advance and retreat cause major changes on coastal zones. One of the most basic elements of Integrated Coastal Zone Management is the accurate determination of coastal line. For this purpose, tools such as remote sensing, photogrammetry, terrestrial measurements, GPS technology and LIDAR systems, which have been actively used in recent years, are used. In this study, the use of LIDAR technology in order to examine coastline changes was investigated. The coast line was automatically determined using LIDAR measurements of the same area from 2007, 2008 and 2009, and change analysis was made.

Keywords: *coastline, coastal zone, coastal changes, coastal management, remote sensing, LIDAR*

1. Introduction

Coasts are the areas where natural and artificial changes occur most frequently. Due to being in the interaction zone of sea and land environments, the coastal zones are greatly affected by the natural changes. Moreover, the fact that the coastal zones were used by humans for settlement, housing, economy, and transportation purposes throughout the history caused artificial changes in these areas as well (Sesli, 2006; Kuleli, 2009; Doker, 2012). Distinguishing land and water in black and white aerial photographs, especially where the waters are blurry and muddy, required extensive terrestrial efforts. Also, the fact that aerial photographs were not digital made it difficult to extract information and caused mistakes. Much larger areas could be included in real time all at once and much more detailed information on earth could be obtained using digital images with high spectral resolution (Alesheikh et al., 2007; Sesli, 2010; Görmüş et al., 2014). In line with these developments in remote sensing imaging systems, use of LIDAR (Light Detection and Ranging) technology has become more common in various engineering practices. LIDAR data has numerous advantages. It is a versatile technology used in atmospheric studies, sea level measurements and glacier studies. LIDAR is used in the production of maps of terrains with different characteristics. This technology provides high accuracy and high point density of digital elevation model. LIDAR is much more effective on areas with slight elevation differences and relatively low-intensity vegetation (Wehr and Lohr, 1999; Yılmaz and Yakar, 2006). The U.S. National Oceanic and Atmospheric Administration (NOAA) used LIDAR to map the United States'coastal boundary in order to define the nation's legal shoreline (White, 2007).

1.1. Problem Statement

Coastal management is usually created in order to solve problems arising from use of the coastal zone. For the purpose of identifying and solving problems, some countries and international organizations ("UN Department of International Economic and Social Affairs (1982)", "UNEP (1995)", "IWICM (1996)", "The Organization for Economic Co-operation and Development (OECD)" have developed guidelines about the content of coastal zone management (Kay and Alder, 1999). Some changes occur on coastal lines naturally. As highlighted by Gibeaut et al., (2001) divides changes that occur in coastal line into three categories: long-term changes, short term changes and episodic changes. In this context, short-term changes take place in a time period of 5 to 10 years. Episodic changes are defined as sudden changes that occur as a result of natural events, such as storms and tsunamis. While long-term changes affect the entire coastal zone to the same degree, short-term change may cause the coast to advance on one side and to retreat or remain unchanged on the other side, with intervals of a few kilometres. Due to the natural characteristics of low coasts, these changes occur as advance or retreat of the coast as a result of natural conditions such as waves and winds. Coastal zones, which form the intersection line of the land and the sea, have a highly variable natural structure and are affected by almost all changes that take place near them.

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Coastal zones are always the centre of attraction, because they can be used as a living space for humans, provide various opportunities for industry and commerce, are used as a waste discharge area, or for food production, contain natural beauty, can be used for education and national defence purposes. In spite of these opportunities provided by the coastal zones, the results of human activities are extremely devastating (Bostwick and Ketchum, 1972; French, 1997). The first attempts in the management of coastal areas were launched by developed countries. In 1972, Coastal Zone Management emerged in the USA for the first time. It is widely accepted that measures taken in accordance with the Coastal Zone Management Act made in 1972 were more effective compared to traditional approach (Post and Lundin, 1993). It could be suggested that it was one of the indirect benefits of the Stockholm Human and Environment Conference that the coastal management was subject to legal regulation for the first time (Cicin-Sain ET AL., 1995). After this first initiative in the USA, many countries began to make an effort in this direction in the early 1980's (Leitmann, 1998). This approach, the foundations of which were laid in 1972 with the new coastal management law made in USA, can be called Integrated Coastal Zone Management. Changes that take place in coast lines require long-term data. GIS and remote sensing (RS) methods are preferred in the evaluation of this data. Remote sensing is also one of the most efficient methods to detect coastal change (Vinodkumar ET AL., 1998; Kostiuk, 2002; Zhu, 2001; Aydinoglu and Gungor, 2010).

1.2. Coast Line Concept

Coast line, with its simplest definition, is where the land and the sea meet. Another definition of coastline is the natural line that is formed by the conjunction of points where seas, lakes and rivers touch the land mass, except for their overflowing states, and changes according to meteorological events (Akıncı et al., 2012). If this line didn't change, it could be easier to define it. However, the dynamics of the natural events that shape the coast is quite high, although it changes depending on place and time. Thus, the line that connects the land and the sea creates an interactive area between the land and the sea with the effects of sand accumulations, tides and storms, and this area continues to change in a decided manner (Sesli et al., 2003).

1.3. LIDAR (Light Detection and Ranging) Technology

Generally, remote sensing 'receiving physical and spatial information about the objects without touching them, but by using satellite images and spatial and qualitative sensing of objects' is the description (Lillesand and Kiefer, 1994; Eastman, 2003; Jensen, 2005; Demirkesen, 2007; Kim et al., 2013; Epifânio et al., 2013; Bayram et al., 2008). LIDAR is the laser scanning sensing system used for receiving high precision spatial data. This technology started to develop at the end of 1960's and the first commercial LIDAR system was released in 1993 aiming topographic mapping. The LIDAR working principle is measuring the time of the laser signals, send from the laser scanning system and reflected from the object's surface, to go back to the receiver (Petrie and Toth, 2009). By using the GPS/IMU system, the location and coming back information at the time that the laser signal was sent is measured to figure the X, Y, Z coordinates of the object. In modern LIDAR systems the laser signal at the same time records the intensity information to form an 'intensity image'. The intensity image is used in order to classify the locations with the same hight information and to extract the features of the objects (Baltsavias, 1999; Schenk and Csatho, 2002; Habib, 2008). Laser is an important component of the LIDAR system. The laser uses the electrical and chemical energy as input in order to create an optical energy. The biggest problem during this cycle is that only 1-10% of the laser signals have enough energy when they get back, so there is a substantial loss of energy. Despite this, the signal with many wanted qualities is produced. These qualities are; L: high radiance, λ: short wave length, $\Delta\lambda\tau$: narrow spectral width, $\Delta\lambda\tau$: short pulse time, PRT: pulse repetition time, Qt: laser signal resolution. These qualities provide these advantages. Wide L and short wave length provide the target to be a small area. Wide L causes high flight altitude. The high vertical line is an outcome of low pulse rate and small τ. lastly, usage of narrow spectral width and checking the radiation source, enables to work at the your night time (Goldstein et al., 1988; Yılmaz and Yakar, 2006). There are many products obtained from the data received from the LIDAR systems. These products as; Digital Elevation Models (DEM), Digital Terrain Models (DTM), Triangulated irregular network (TIN), Contours, Shaded relief maps and Slope maps. When looking at the products of the LIDAR data, it is easily seen that the area of application is wide. Depending on the application, LIDAR system when compared to the ground and photogrammetric measuring methods, is a complementary technology. In many surveying applications the aerial laser scanning technology is used together with digital cameras, multispectral scanners and thermal cameras which contain other detectors. This system which has properties that cannot be gathered from other systems is used in different areas. LIDAR data which have extensive areas of usage are used for different purposes in different application areas. LIDAR scanning system which is used mainly for determining three dimension surface area and field surface characteristics usually serves these areas (Ekercin and Üstün, 2004; Andersen et al., 2005; Blackburn, 2002; Hyde et al., 2006; Nelson et al., 2005; Streutker and Glenn, 2006; Thoma et al., 2005; Suarez et al., 2005; Zhou et al., 2004) such as; Digital Mapping, Land Use Determination, Stream Monitoring and Evaluation, Natural Environment Analysis, Renewal Activities, Forest Management, Disaster Planning, Transportation, Telecommunication Panning, Urban Development and Coastal Management.

1.4. Aim of the Study

In coastal zone management, determination of coast line and examination of coastal changes are primary and continuous activities. LIDAR is a technology that is capable of creating high density digital elevation data with geometric properties at almost the same accuracy as terrestrial measurements and faster than aerial photogrammetry.

Compared to terrestrial measurement methods and aerial photogrammetry, LIDAR requires less field work and has a lower evaluation cost. This makes LIDAR and attractive technology for users who need digital elevation data referenced at required accuracy, with high point density at a low cost (Ekercin and Üstün, 2004). With this study, LIDAR data of a sample region belonging to years 2007, 2008 and 2009 were processed and the coastline was determined automatically. LIDAR data belonging to the aforementioned years were collected during the same period (in April). Thus, the effects of seasonal change were reduced to a minimum level. The coast line was tried to be determined automatically and the changes in the coastline were interpreted.

2. Materials and methods

The coastal zone between the coordinates of 33^{o} $27^{'}$ $45,0037^{''}$ N, 117^{o} $41^{'}$ $16,9687^{''}$ W and 33^{o} $26^{'}$ $11,898^{''}1$ N, 117^{o} $38^{'}$ $24,8310^{''}$ W was selected as the study zone. The LIDAR data of the coastal zone between Los Angeles and San Diego, CA, USA, provided by "National Oceanic and Atmospheric Administration (NOAA)" constitute the study material. Also, the satellite images of the same are at a resolution of 1 m provided by "National Agriculture Imagery Program (NAIP)" were used as well (Fig.1 and 2).

Fig. 1. Location of study area.

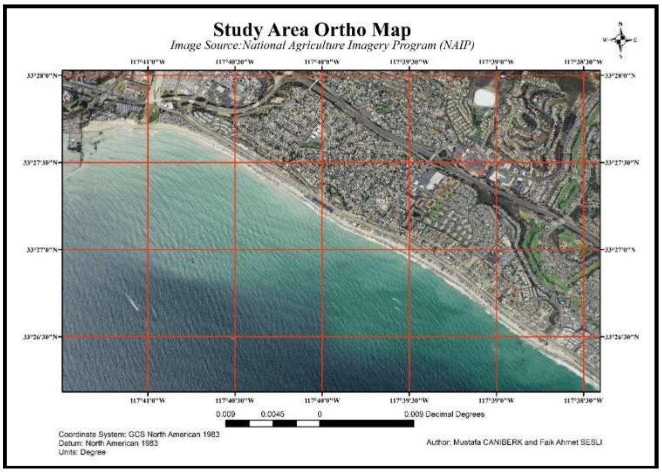
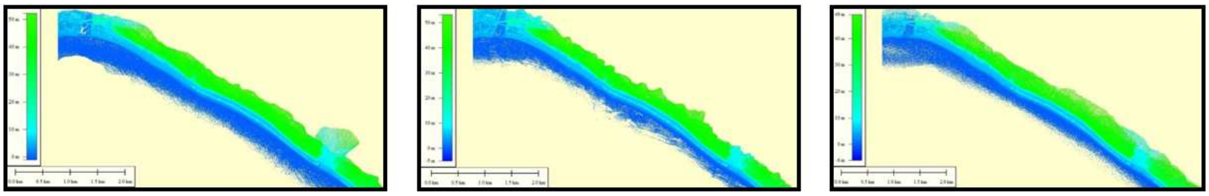


Fig. 2. Downloading the data of the study zone at a resolution of 1 m.

The LIDAR data provided was in ".laz" format. This is the compressed format of raw LIDAR data and can be opened with LasZip software, which can be found at "http://www.laszip.org/". "Global Mapper" software was used to obtain Digital Surface Model (DSM) from LIDAR data.The coast line was determined automatically using the DSMs produced with this software. The LIDAR data of the study zone were downloaded from "http://coast.noaa.gov/digitalcoast/". The processed LIDAR data can be seen in Fig. 3. The compressed LIDAR data were opened and raw LIDAR data were obtained. This LIDAR point cloud data were collected in "Long Beach" from a lane of 5 km in length and 500-700 m in width and at low tide conditions along the beach.



(a) (b) (c)

Fig. 3. The raw LIDAR data of the study zone (a) 2007, (b) 2008, (c) 2009.

The data were collected using an "Optech Inc. Airborne Laser Terrain Mapper (ALTM) 1225" device and in a way that there was 6-8 points in one square meter. For the LIDAR data collected, the planimetric accuracy was reported to be 10 cm and the height accuracy was reported to be 15 cm. When sent to the surface, laser signal can hit several points. While some signals go directly to the ground, some are reflected from natural and artificial details first. The sensors can collect both data depending on the system settings. This is usually described as "first signal returns first, last signal returns last". Usually, topographical maps and digital surface model are based on the elements that return last. However, the signals that return first are used in DSM production. The laser signals that return first must be used because DSM data contain all natural and artificial details in the zone. For this reason, the signals reflected first from the LIDAR point cloud were filtered before DSM production**.**

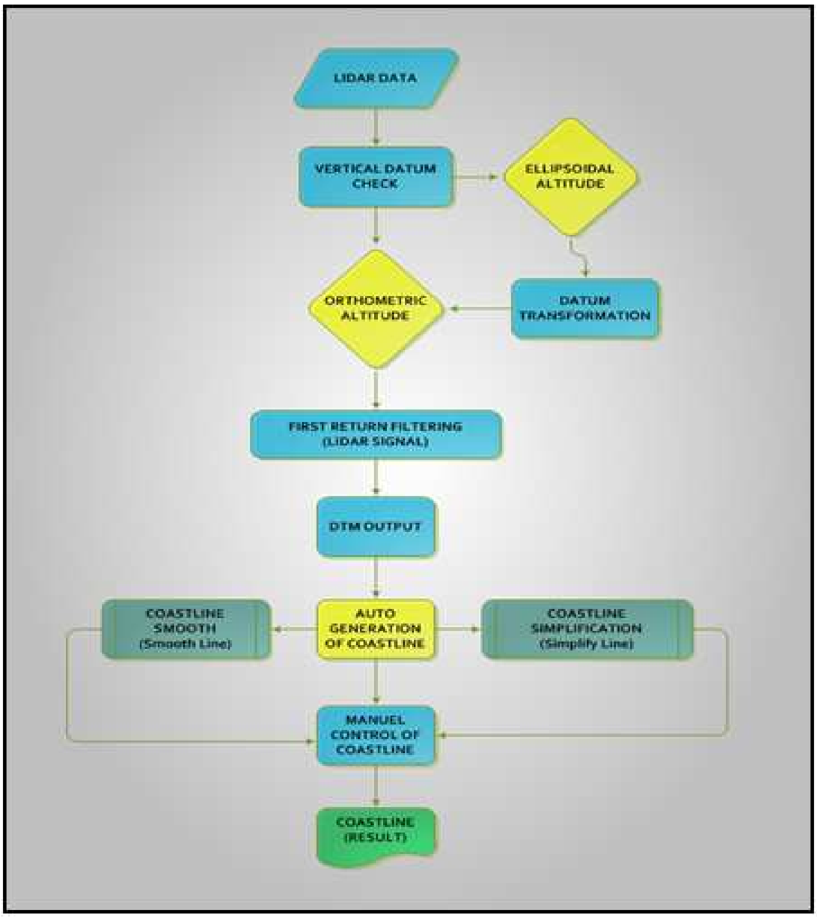
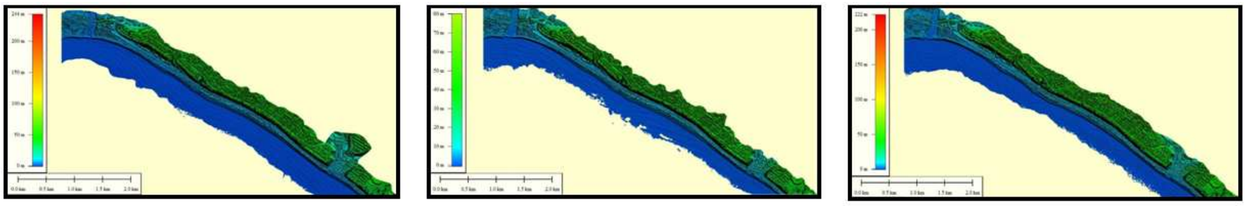


Fig. 4. Flowchart used to determine the coast line from the LIDAR data.

Contours are lines that show heights above the sea level. Each contour, which is one of the basic elements of topographic maps, represents the points located at the same height above the sea level. With this approach, the zero contour line represents the mean sea level. "Coast Line" concept basically corresponds to the zero contour line. The most important point to note here is that the vertical datum is known. The reference information of the LIDAR data used in the study is available in the metadata file. Examining the metadata, it is seen that the reference is “Altitude Datum Name: North AmericanVertical Datum of 1988 (NAVD88)”. NAVD88 datum is a system that was established to identify the orthometric height. In short, NAVD88 datum uses the local mean seal level as the reference point. A flowchart was designed and implemented to automatically determine the coastal line from the LIDAR data (Fig. 4). First of all, the raw data were filtered according to the values of the first reflection. After this process, filtered data were used to produce DSM. After the vertical datum identification in the LIDAR data, the DSM data of the study zone according to years was produced (Fig. 5). The coast line was determined automatically using the DSMs produced (Fig. 6).



(a) (b) (c)

Fig. 5. The digital surface model of the study zone (a) 2007, (b) 2008, (c) 2009.

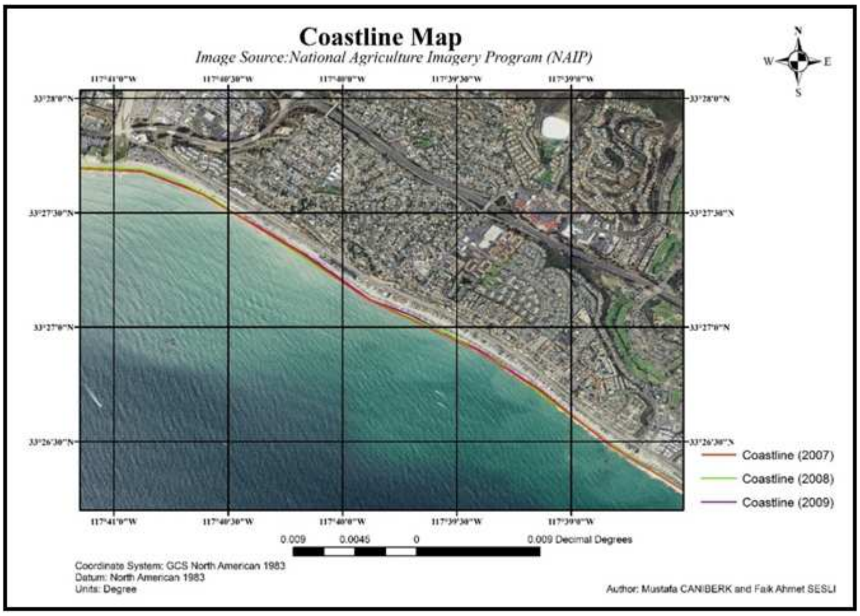


Fig. 6. Automatically determined coast lines.

3. Results and discussion

The coastal zone of the study zone in 2007, 2008 and 2009 was measured and the amount of change was calculated. These values are given in Table 1.

Tab. 1. *Coastal zone and amount of change.*

Year	Coastal Zone (Hectares)	Coastal Change (Hectares)	Change Ratio
2007	29,89	--	--
2008	28,93	-0,96	3,21 %
2009	28,45	-0,48	1,66 %
TOTAL		-1,44	4,87 %

It is seen from Table 1 that the coastal change for the period of two years was a coastal retreat of 1,44 hectares. It is understood from Table 1 and Fig.7. that the coastal change was in the form of a retreat. Considering that the study zone was approximately 5 km long, it can be said that the coastal retreat was 0,288 hectares (2880 m^2) for the coastline of 1km. The satellite images of the study zone show that the settlement started approximately 50 m away from the coast and a highway and a railroad were available 125 m away from the coast.

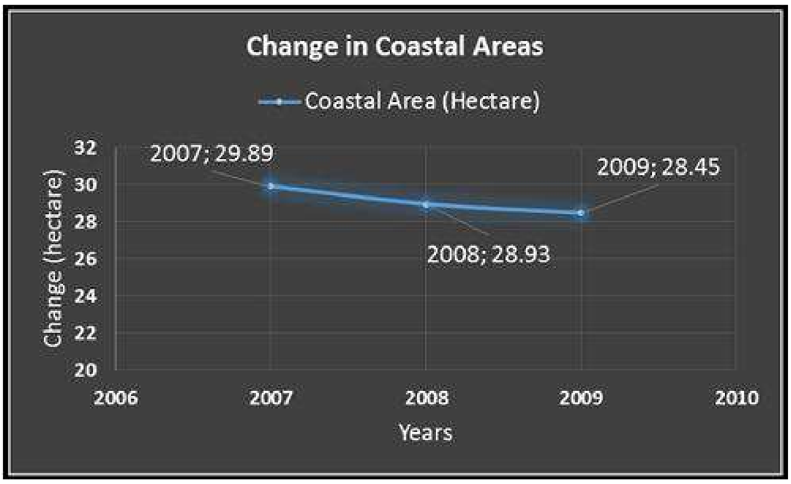


Fig. 7. Coastal zone change according to years.

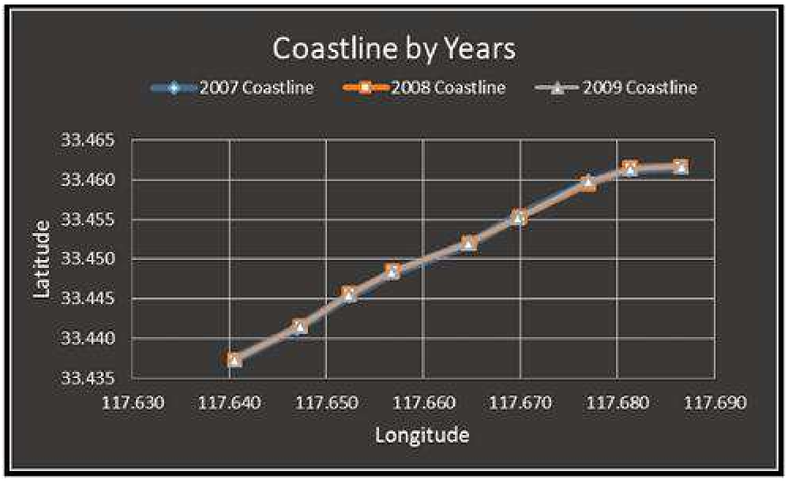
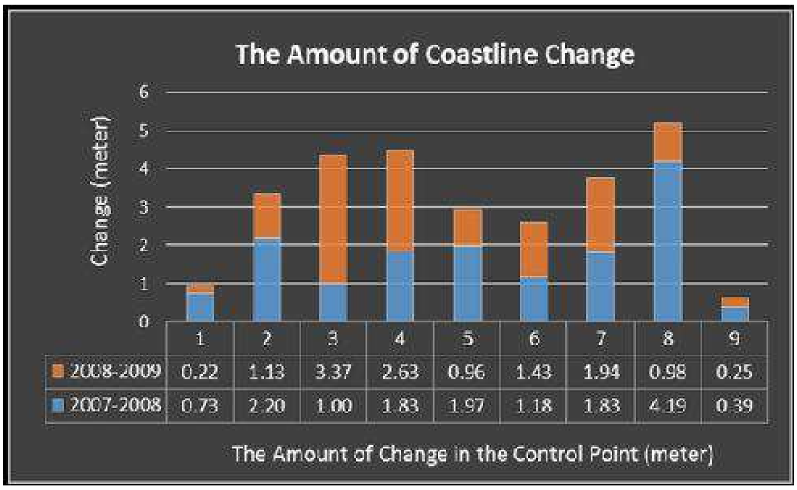


Fig. 8. Coast line changes according to years.



	1	2	3	4	5	6	7	8	9
2008-2009	0.22	1.13	3.37	2.63	0.96	1.43	1.94	0.98	0.25
2007-2008	0.73	2.20	1.00	1.83	1.97	1.18	1.83	4.19	0.39

Fig. 9. Coast line change rate according to years.

The change in the coastline is shown in Fig. 8 and the coastal changes in the 9 checkpoints along the coast line determined with intervals of approximately 500 m are given in Fig. 9. Examining the figure, it is seen that there was a change of about 1-5 m. As can be seen in the topographic map produced within the framework of this study (Fig. 10), a change in the coastline between 2007 and 2009 due to recent human activities was not observed. Thus, the coastal changes are thought to be due to physical factors. The change in the coastline was observed for a limited time period and it was seen that the coastal change for the period of two years was within the range of 1-5 m. These coastal changes can be said to be mainly caused by natural factors and in a normal range.

In the light of the findings, in spite of high population density, the presence of a railroad (Pacific Coast Railway), a highway (Pacific Coast Highway) and a port (Dana Point Harbor) near the coastline, it can be said that the changes in the coastline was at an acceptable level and these structures did not have adverse effect on the coastline (Fig. 10).

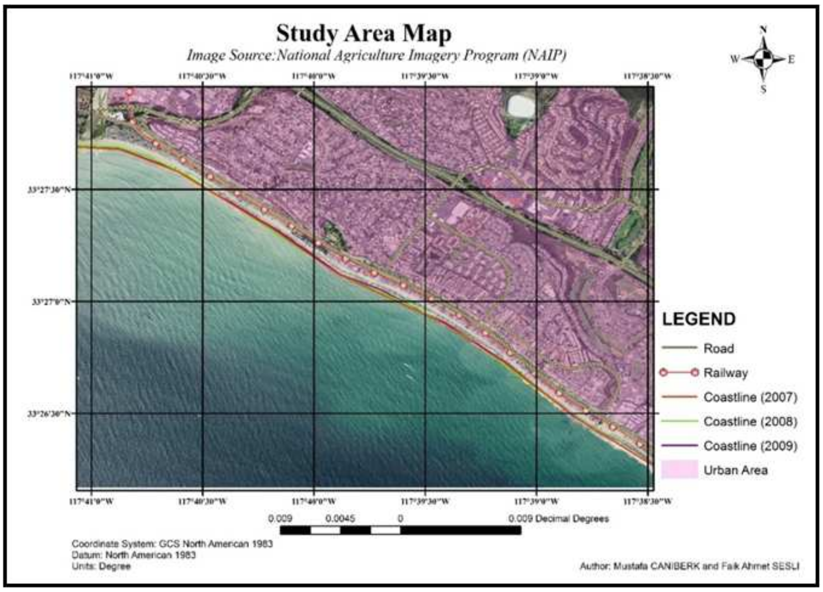


Fig. 10. Topographic map produced for the study zone.

4. Conclusions

It can be suggested that LIDAR systems are crucial data providers due to their usability in cases where traditional measurement methods fall short in dangerous areas that are hard to access, especially for studies on coastal zones. Also, being independent of daylight and its ability to collect complete data in scanning areas can be considered as other advantages of this system.

In this study, LIDAR systems, which have been used successfully in various areas, were used to determine the coast line. It is clearly seen that precise determination of coastlines can be made using LIDAR systems, which have high planimetric accuracy. It is possible to use this system in coast line determination activities, which are quite time consuming and full of setbacks due to meteorological conditions, especially in field works, when traditional methods are used, and systematically collect processable data.

It is possible to classify the actual and possible changes in the coastal zones as due to natural factors and due to human factors. On which part of the zone the change occurred is just as important as the reason of the change. The changes in the coastal zone are caused by coastal advance or retreat in the coastline or the coastal zone. Due to being in the interaction zone of sea and land environments, changes that occur in coastal zones are two sided. In these coastal changes, physical factors such as wave erosion, wave accumulation, material accumulation of watercourses and sedimentation are effective. Human induced changes occur due to activities such as coastal fillings in order to obtain land, construction of ports and harbours and interventions to the coastal zone to build transport routes. Positive results of the efforts of the USA regarding coastal management beginning from 1970's were seen in this study.

The coastlines show a structure that changes over time. Coasts must be measured periodically to monitor these changes. At this point, it is thought that the use of LIDAR, which is a fast, efficient and highly accurate, will be very useful and fast solution.

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