New technologies in geoinformation science and technology for sustainable management and development in the mountainous area of Naxos

Ioannis (John) N. Hatzopoulos
Professor and director of Remote Sensing and GIS Laboratory
University of Aegean, Dept. of Environmental Studies
University Hill, Mytilene, 81100
Ihatz@aegean.gr

Abstract. *A great advancement has happened recently in geoinformation science and technology which gives more opportunities to provide data and manage information especially for remote and mountainous areas for sustainable development.*

Classical geoinformation areas of remote sensing and Gis have been both evolved using new technologies.

This presentation will discuss issues related to those technologies particularly those that can be used for sustainable development in such areas.

Technologies such as airborne laser scanning can provide information on vegetation mapping in three dimensions being able to estimate the biomass distribution and volume with high accuracy. Information on biomass could be applied on models such as: erosion, desertification, natural hazards, etc.

This type of technology is a combination of two other technologies such as global positioning system (GPS) and inertial measuring unit (IMU or INS). Other technologies such as photogrammetry and satellite imagery have also been advanced providing useful data for this kind of applications. Gis technology has also being advanced to perform the classical management of geospatial data and recent advances allow more application models to be directly incorporated within the Gis system so that to make appropriate data processing and derive useful information for sustainable development.

This paper will also present such information on water management and mapping of hiking trails in the mountainous area of the island of Naxos.

Keywords. GIS, LIDAR, Remote Sensing, DTM, Sustainable development.

1. Introduction

The discussion will start with basic principles of airborne topographic Lidar and its advantages in digital terrain modeling (DTM) data extraction, as well as, vegetation and forest resources mapping. Then it will be discussed some of the technologies for digital terrain modeling (DTM) such as Interferometric Synthetic Aperture Radar (Ifsar). Finally there will be shown some applications of DTM in management of water recourses and in mapping hiking trails as a contribution to the sustainable development in the mountainous area of the island of Naxos.

2. Airborne Lidar – basic principles

A general concept of topographic Lidar (LIDAR = Light Detection and Ranging) is

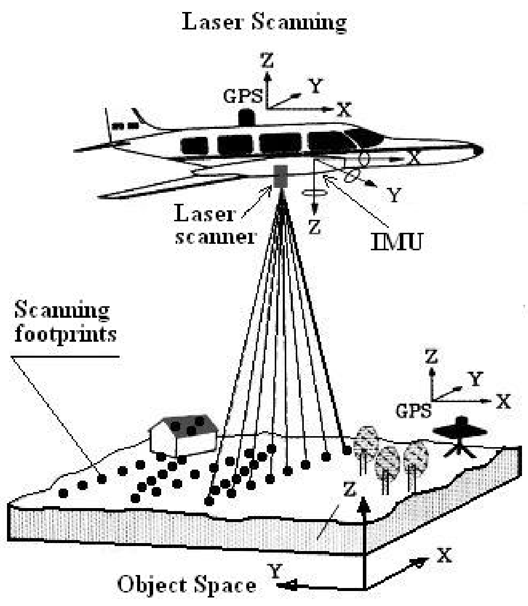

Figure 1. General concept of topographic Lidar.

shown in Fig. 1. As shown in Fig. 1, [3], [6], there is a laser scanning device with a rotating mirror located in the airplane. The position of his device is measured and recorded in real time by a global positioning system (GPS) and an inertial measuring unit (IMU) system. Differential GPS measurements are controlled by using one more GPS device at a known ground station. Airborne Lidar systems use an active laser beam of coherent electromagnetic radiation centered in the near infrared spectrum region for ground measurements and in the visible spectrum region for underwater measurements. Measurements are actually spot elevations as shown in Fig. 1 at a frequency ranging from 10000 Hz to 50000 Hz.

Geometry of Lidar system is shown in Fig. 2 [6] and the position and orientation of the laser beam is computed from GPS data (X_a, Y_a, Z_a), IMU data (X_m, Y_m, Z_m, *roll, pitch, heading (yaw)*), and the well known distances (AM - *Lever arm*), (AL), and (ML) from laboratory calibration measurements. The distance (LG – *boresight*) is computed using recorded time of return beam by Lidar system. Actually Lidar data include ignition time of pulse which is curried out by used Lidar measuring frequency (10 – 40 KHz) and recorded time for one or more beam returns. The ancillary data of GPS and IMU are also recorded in real time and are used to determine the position of mirror L and boresight orientation.

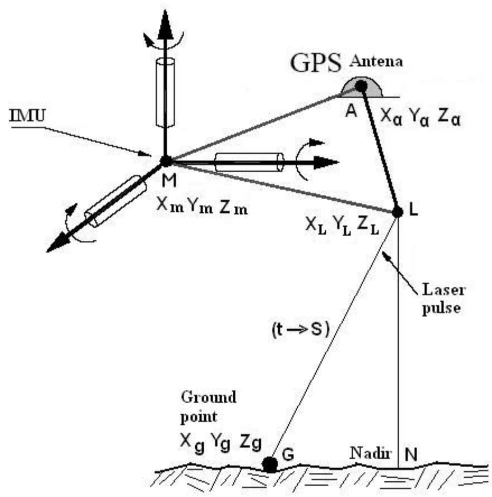

Figure 2. Geometric analysis of topographic Lidar.

Typical specifications for Lidar measurements are shown in Table 1, [3], [6]. The elevation accuracy of Lidar data as shown in Table 1, is quite high (~15 cm) as compared to the horizontal accuracy (~10 – 100 cm). This

Table 1. Specifications of topographic Lidar

Specifications	Typical value
Spectral wavelength	1.064, 1.5 μm Topo / 0.532 μm Hydro.
Repeat rate	5 – 33 Khz , Max 50 Khz
Pulse energy	100s μJ
Pulse width	10 ns
Beam deviation	0.25 – 2 mrad
Scanning angle	40^o – max 75^o
Scanning rate	25 – 40 Hz
Scanning patterns	Zig – zag Parallel Ellipsoidal Sinusoidal
Frequency of GPS measurements	1 – 2 times per second
Frequency of IMU	50 Hz – Max 200 Hz
Flight altitude	100 – 1000 m – Max 6000 m
Dimensions of ground footprint	0.25 – 2.00 m (1000 m altitude)
Multiple returns of single beam	1 – 5
Ground grid dimensions	0.5 – 2.00 m
Ground elevation RMSE	15 + cm
Ground horizontal RMSE	10 – 100 cm

creates a problem to determine precisely the brake lines of ground features such as river banks, outlines of features, etc. For that reason and because Lidar is a relatively low cost technology, Lidar is used together with other remote sensing technologies such as aerial photography and satellite imagery. In this way remote sensing together with Lidar is an upgraded system to provide complete and accurate land cover information into the three dimensional space [10].

2.1. Lidar – Topographic elevation data

Lidar is capable to gather a large volume of elevation data which in combination with remote sensing data provide a complete coverage of topographic surface in three dimensions with high accuracy. Lidar is using an active sensor and can perform measurements day or night under any weather conditions with the limitation that there is visibility between sensor and target. Elevation data for DEM can be collected on topographic surface even if it is covered by vegetation.

2.2. Lidar – Forestry

The most important application of Lidar in sustainable development of natural resources is its application in forestry [1], [2], [5], [8]. In Fig. 3 it is shown that a single Lidar pulse may have recorded up to 5 returns from various heights of

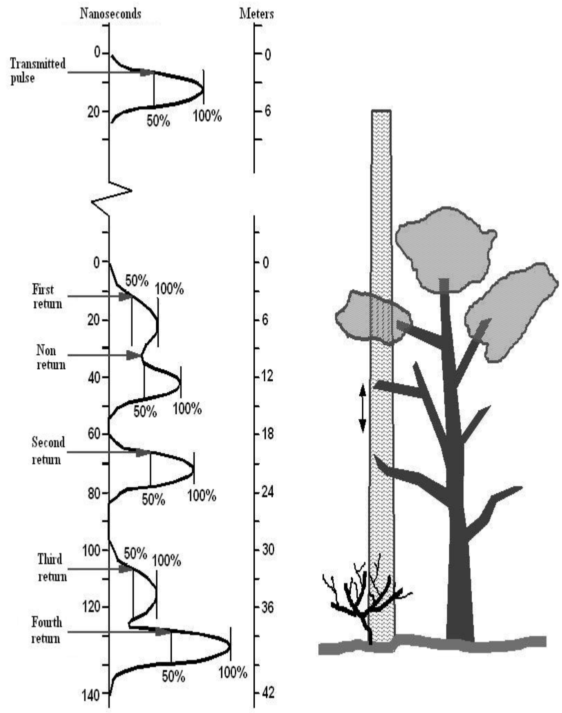

Figure 3. Lidar vegetation mapping.

vegetation cover. In this way vegetation can be mapped at various heights and various types such as trees, brass, bushes, etc. The use of Lidar in vegetation mapping helps to estimate:

a) Geometric characteristics of vegetation such as the high and width of trees.
b) Monitoring of tree growth rate for planted areas with trees.
c) Monitoring of wooded areas used for sustainable timber management.

Other processing methods of Lidar data are using stochastic models [1], [2], [10], taking advantage of multiple pulse return to determine various parameters which are useful in forestry. Such parameters are determined as shown in Fig. 4 where foliage density is determined and is shown by its vertical profile.

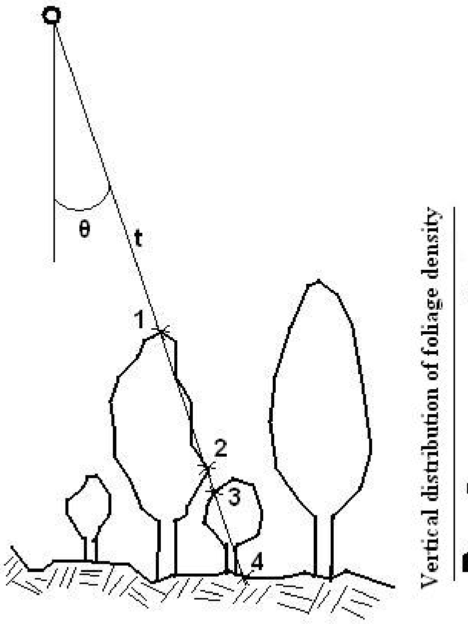

Figure 4. Lidar vertical distribution of foliage density.

Such methods help to determine:

- Simultaneous mapping of tree canopy and ground surface
- Vertical profile of tree foliage
- Estimation of tree density
- Detail information for composition and structure of foliage.

2.3. Lidar – coastal engineering

Lidar has significant applications in coastal engineering being a technology which can perform mapping over sandy beaches and sand dunes. Coastal processes are dynamic and must

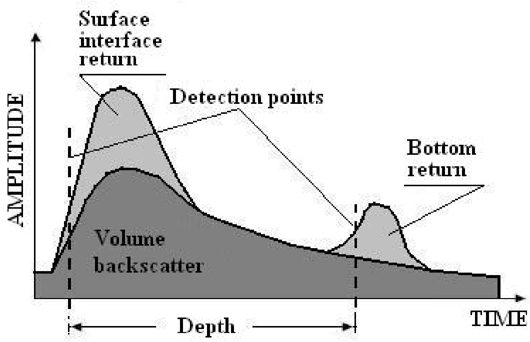

Figure 5. Hydrographic Lidar

be monitored at frequent intervals for a better management of the area particularly on maters of maintenance and sustainability. Topographic Lidar together with hydrographic Lidar can be used together for simultaneous mapping of coastal zone in both land and shallow water areas. As shown in Fig. 5 hydrographic Lidar can be used to do bathymetric mapping [3], [6], for up to 50 meters water depth of clear water.

2.4. Lidar – data processing

Processing of Lidar data deals with elimination of points which do not correspond to the target surface which is measured. Lidar data can be used for real time rough estimates of elevation data or, for precise estimates of post processed data. Post processing originally forms a cloud of elevation points to provide a synoptic view of the project and requires mainly two levels of processing. The first lever uses an automatic algorithm which eliminates 90% of wrong elevation points. The second level works manually with the operator's aid to eliminate the rest of 10% of wrong elevation points. It must be noted that manual processing absorbs 40% of resources of total costs of a Lidar project.

Lidar projects may be found in web references [12], [13] and [18].

Lidar data may be found in web references [14], [15], [16] and [17].

3. Interferometric Synthetic Aperture Radar (IFSAR) technology.

Ifsar technology is based on intersection of ground points by two microwave (RADAR) pulses. As shown in Fig. 6 [3], [6], two beams K_1

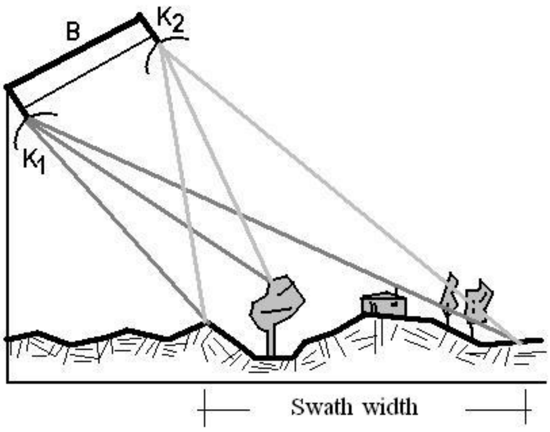

Figure 6. Principles of IFSAR system

and K_2 from the ends of a baseline B transmit microwave coherent pulses covering a ground swath width and the back scatter is received and the time is recorded. Recorded time defines the distance to the corresponding target and thus for each target there are two distances recorded one from K_1 antenna and one from K_2.

Ifsar systems include GPS and IMU systems in a similar way as those are used in Lidar systems (see Fig. 2).

Ifsar systems are operating day and night and under all weather conditions. The system is usually mounted in a jet plane and can cover relative large areas as comparing to Lidar systems but provides less accuracy.

Usually Ifsar systems work on a single band and perform either top of the vegetation mapping or ground surface mapping. P–band is used for example for ground surface mapping while X–band is used for top of vegetation mapping. However there are systems which use both bands to map in a single flight both the top of vegetation and the ground surface. Such systems have a total of four tranceivers, two for P-band and two for X-band.

It must be noted that a single target point on the ground is viewed from many transmitted pulses of same transceiver from different locations of the course of the aeroplane. Synthesis of those pulses to define a single target point defines the synthetic part of the Radar system.

4. GIS technologies

New technologies as described for data acquisition to create three dimensional remote sensing data of land cover are constantly developed and used for a wide range of applications. Parallel to this GIS systems are also evolving into more sophisticated systems. It must be noted the role of software on such technologies which represents almost 98% of total costs and total processing performance.

GIS is used to manage a large volume of data distributed over the geographical space and deal with data values and geographical locations of such values. Management includes input and output operations, data storage and retrieval and almost unlimited ways of data processing to derive useful information. Output operations include data visualization options such as thematic map and three dimensional presentations or even virtual reality presentations.

Those capabilities of GIS systems make them particularly useful tools for sustainable development projects. Such projects are worked out over geographic locations and geographical space is an integral part of the project. On the other hand many phenomena which take place over the geographical space are particularly important for sustainable development. Such phenomena include weather and climate conditions, human interaction, economics, environmental activities, water cycle and other natural processes. All such phenomena are described with various models and GIS systems provide all kinds of tools and facilities to run such models. Many of those models are integral parts of GIS systems while others are either on the way of integration or communicate in a loose coupling way.

5. Application of new technologies for sustainable management and development in the mountainous area of Naxos.

There are two applications to be reported here, one deals with a search for locations to construct small reservoirs along a drainage network within a water basin, the other deals with detection and attribute determination of hiking trails. A map illustrating the geophysical properties of island of Naxos is shown in Fig. 7.

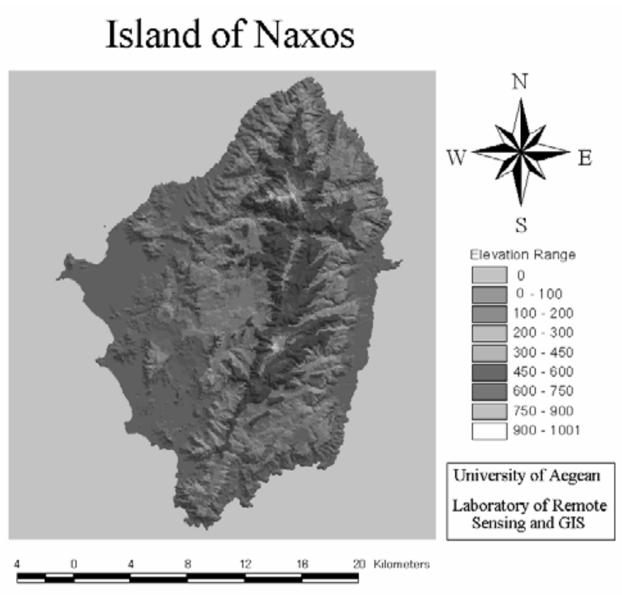

Figure 7. Geophysical properties of the island of Naxos.

There are two mountain tops raging about 1000 meters in elevation each. Mountain Zeus is located in South and mountain Koronos is located in North. These mountain tops are part of a mountain ridge which is expanded along the spine of the island having a North – South orientation. This mountain ridge creates many drainage basins with a lot of watersheds and provides a great variety of mountain trails.

5.1. Small water reservoirs for water resources management

Small dams have already been constructed in the area of Aperathou of Naxos and they have been reported by Glezos Manolis, [4]. The great success of such work has given the idea for further study to locate the areas for such structures to be built [7], [9].

Precipitation surface water in Greek islands of Aegean Sea is very valuable and it is the main source of water supplies in such areas. People since thousand years ago usually gather such water from the roofs of the buildings and store it in small reservoirs located in the basement of the house. Although this process helped people to cover part of their needs in water supplies, only a small portion of surface water was saved, and the rest will go down to the sea. Modern technologies such as GIS can help us to make a better water resources management so that to minimise the amount of water that goes to the sea. The idea is to locate places to build small dams which could hold a minimal amount of water (for example, 50 m^3). They can be constructed by local material such as rocks which is adopted better to the environment and try to hold as much water as possible so that to enrich the ground water aquifer and to reduce erosion and flooding.

Experimental testing was performed in the basin of North East part of the island of Naxos

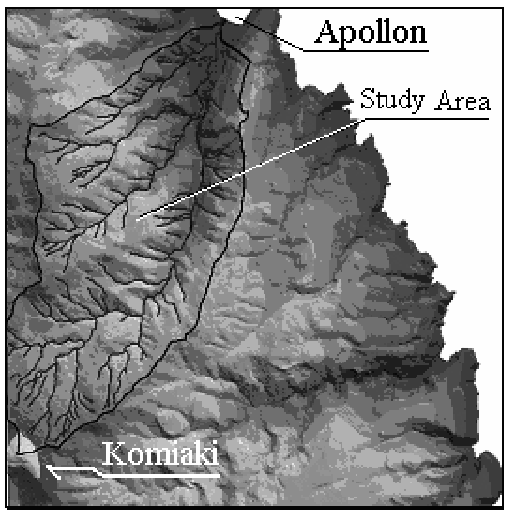

Figure 8. The area of study.

which starts from Apollon village and ends up over Komiaki village (see Fig. 8).

A total of 8 maps of scale 1:5000 were digitized using the ESRI ArcView 3.2 software. Creation of TIN was based on digitization of 4 meter contour line interval stored in a single shapefile.

The following specifications were chosen to search for locations of small dams (see Fig. 9):

1. Height (υ) of dam face to be less or equal to 2m.
2. Width (α) of dam face to be less or equal to 12m having direction perpendicular to water flow direction.
3. Ratio of depth over width (β/α) be greater than one.
4. Volume of water in the dam be greater than 50 m^3.

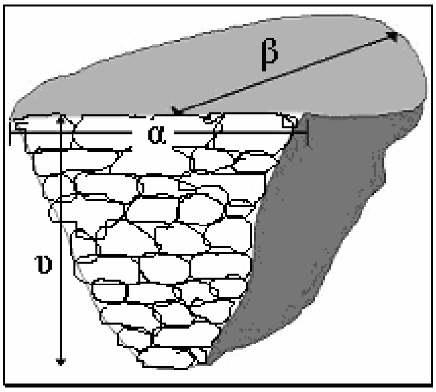

Figure 9. Reservoir dimensions

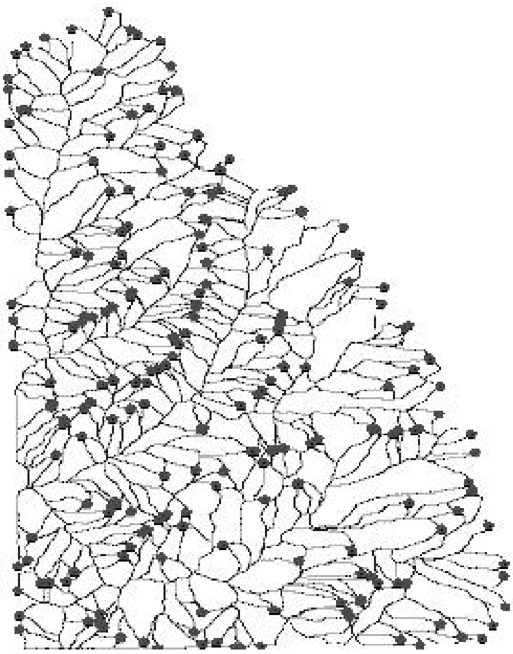

Figure 10. Watersheds and discharge points of region using the ESRI Archydro

Using the Archydro of ESRI (see Fig.10) and meteorological data for the island of Naxos the average monthly volume of waterfall was computed for this particular basin [7], [9]. Taking into consideration hydrological conditions of the region the average run off monthly volume was computed to be **189498 m^3/ month** [7], [9]. Consequently, knowing from Archydro the mesh of accumulation of flow and the accumulation in a cell located over and under the stream, then the volume of water in the dam was computed as well as the sum that will flow further below. In this way it can be decided whether or not it is necessary to create successive dams so as to avoid a great loss of rain water.

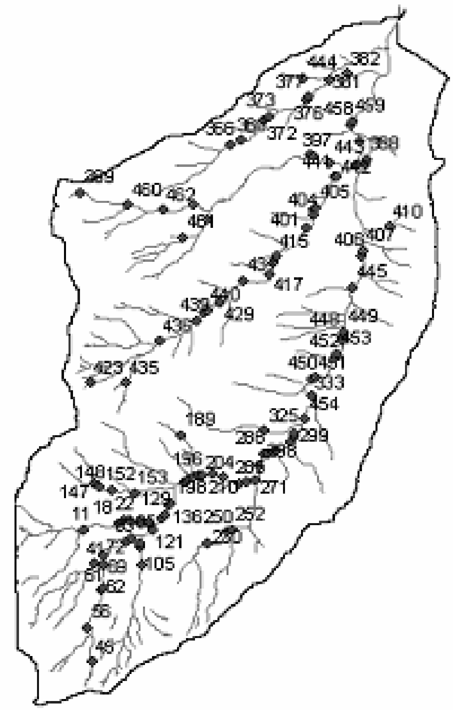

Figure 11. Location of 107 small reservoirs

In order to compute the volume of water in each small dam, the volume of pyramid was used (see Fig. 9). The area of dam (A_d) is the pyramid base and the height of the dam face (υ) is the height of the pyramid and the volume is computed as follows:

$$V = (1/3)(A_d)(\upsilon)$$

The area (A_d) was measured using X-tools (see Fig. 12), the height is taken **υ = 2 meters**. Dams are located along creeks and the volume of water in a dam is subtracted from accumulated flow below the dam, in this way the volume of water reaching the see can be calculated. Throughout this experiment spots for **107 small dams** were located (see Figure 11) and a volume of **9786 m^3** of rain water is anticipated to be held in these dams or **5.16%** of the total monthly rainfall (see

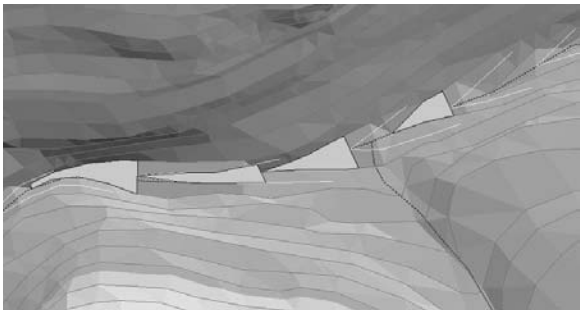

Figure 12. Location of small reservoirs using X – tools along 2m interpolated contours.

Table 2). Table 2 shows Dam ID, Area, reservoir Volume, Accumulated volume upwards the dam, and Accumulated volume downwards the dam.

Table 2. Individual and accumulated reservoir water volume [7], [9]

Dams_ID	Area	Vdams	Vaccumulated	Upwards	Downwards
11	157,263	104,842	5.380,42	5.380,42	5.275,58
18	126,329	84,219	7.986,10	7.881,26	7.797,04
19	85,860	57,240	8.031,29	7.842,23	7.784,99
20	133,144	88,763	8.200,12	7.953,82	7.865,06
22	75,939	50,626	8.258,46	7.923,40	7.872,77
23	101,049	67,366	8.362,50	7.976,81	7.909,44
25	75,315	50,210	8.614,84	8.161,78	8.111,57
…	…	…	…	…	…
121	106,089	70,726	18.329,0	17.555,9	17.485,2
127	128,262	85,508	28.531,1	27.103,5	27.018,0
460	87,965	58,643	3.346,51	3.275,42	3.216,78
461	96,662	64,441	2.314,46	2.314,46	2.250,02
462	77,474	51,649	7.456,80	7.327,07	7.275,42
Total		9786,06			

5.2. Detection and attribute determination of hiking trails.

The same region of the Komiaki – Apollon basin shown in Fig. 8 was used to study the hiking trails. Such studies are greatly facilitated by using remote sensing images together with Lidar surveys to detect and locate existing hiking trails.

The island of Naxos and this particular region before 1960 did not have car driven roads and all transportation in the area was performed through hiking trails using mules and donkeys. However, there is a quite dense network of hiking trails all over this region. The existing maps of 1:5000 scale were produced by the Greek Army Geographical Service using aerial photographs taken in late 1980. However, most of existing trails are shown on the 1:5000 scale maps. For this reason trails were directly digitized from the 1:5000 scale maps. The 4m contour lines as mentioned in paragraph 5.1 were also digitized and an appropriate TIN was developed.

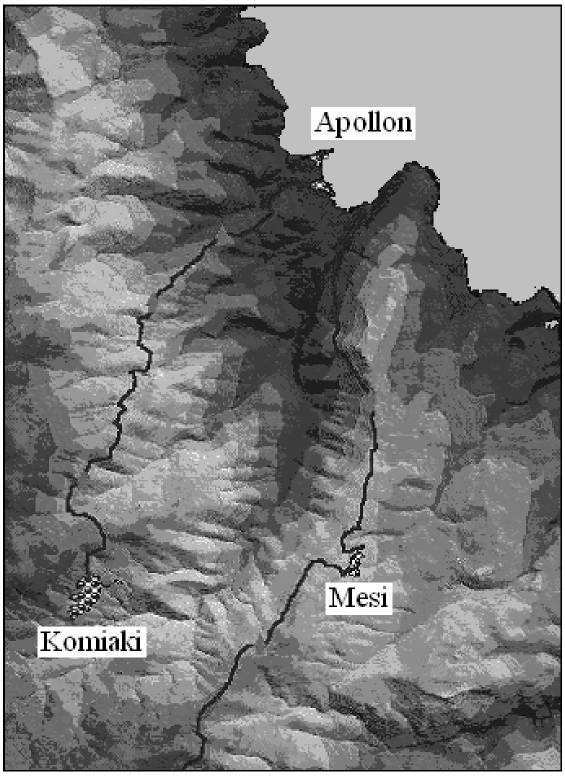

Figure 13. Location of two hiking trails in the basin of Komiaki - Apollon.

As shown in Fig. 13 [11], out of a dense trail network two significant trails were located. The first one is located in the West part of the basin and connects Apollon with Komiaki. The second one is located in the East part of the basin and connects Apollon with Mesi.

Using GIS technology to process the elevation data, some attributes of such trails can be derived. The most important attribute is the degree of slope along the trail which determines the rank of difficulty. This attribute can be analytically determined as the ratio of elevation difference between two points over the horizontal distance between those points. However, slope changes along the path of the trail and there is an average slope along a specific trail. Slope data can be analytically illustrate in a trail profile which is a vertical section along the trail length. Trails may be ranked by the degree of slope as follows:

a) Slope 1% - 3% Easy
b) Slope 4% - 7 % moderate difficulty
c) Slope 8% - 10 % difficult

Slopes greater than 10% must be avoided because of erosion problems unless trails are paved by pieces of rock.

Both trails shown in Fig. 13 provide courses of all ranks of difficulty.

Generally specifications for trails are well analyzed by [11] and are based on work done by [19], [20].

An other attribute to be determine by GIS technology is the vista points which can be found using visualization techniques. Vista points can be chosen by viewing through three dimensional analysis the trail bath using different points of view and different angles of view. Vista points can be also associated with construction of kiosks and other facilities to facilitate hikers.

Other attributes to be managed by the GIS system is all year around cultural activities along the trail path. It is important to understand that the Greek islands maintain an over thirty thousand years of accumulated culture which to a certain degree is still maintained. Such culture includes hospitality, traditional agriculture and quality agricultural products, local customs (dancing, weddings, cooking, etc.), local industry such as wine making, water mills, hand made pottery, production of cheese, local products from wool and text styles, just to mention a few.

The entire trail path can be simulated in a virtual reality product to be distributed for potential tourists.

6. Conclusions

Sustainable development is a serious issue for keeping a delicate balance between production and environmental concerns. However, geoinformation technologies can greatly facilitate such processes, by providing reliable data and tools such as GIS tools to derive useful information.

Modern data acquisition remote sensing technologies such as Lidar, Ifsar, aerial photography, and satellite imagery can provide up to date multitemporal information for mapping and monitoring of most important factors affecting sustainable development.

Emphasis was given to Lidar airborne laser scanning which is an evolving technology for vegetation and biomass mapping. This technology is particularly useful because of its ability to provide multiple returns from vegetation elements located vertically at various heights provided there is optical contact with the Lidar sensor – transmitter system.

The applications to the mountainous area o the island of Naxos showed that water management is important because a lot of water from rainfall reaches the sea causing erosion and flooding in a region where water is a very valuable resource. However new technologies could help to estimate water quantities at specific discharge points of watersheds after a rain fall and help to locate small reservoir structures, which are adopted to the environment and hold water destructive power and facilitate feeding of ground water aquifer.

Hiking trails which carry about thirty thousand years of history in the mountainous areas of Greek islands are also greatly facilitated by such technologies since a wealth of natural and cultural recourses can be managed in a way according to the sustainable development to maximize their attraction to tourism.

7. References

[1] Hans-Erik Andersen, The use of airborne laser scanner data (LIDAR) for forest measurement applications, Precision Forestry Cooperative University of Washington College of Forest Resources. Unpublished Ph.D. dissertation, University of Washington, Seattle, WA.

[2] Andersen, H.-E., J. Foster, and S. Reutebuch. 2003. Estimating forest structure parameters within Fort Lewis Military Reservation using airborne laser scanner (LIDAR) data. In: Proceedings, 2nd International Precision Forestry Symposium. Seattle, Washington. University of Washington, College of ForestResources: 45-53.

[3] ASPRS, David F. Maune editor, 2001. Digital elevation models technologies and applications: The DEM users manual.

[4] Glezos Manolis, 1993, Enrichment of Aquifer using Low Dams for Stream Flow Interception in Mountainous regions, Proceedings, 2^{o} Hydrologic Congress of Greek Committee of Hydrogeology, November 24-29, Volume A’, pp. 99-105.

[5] Harding, D., M. Lefsky, G. Parker, J. Blair. 2001. Laser altimeter canopy height profiles:

Methods and validation for closed-canopy, broadleaf forests. *Remote Sensing of theEnvironment* 76:283-297.
[6] Hatzopoulos J., N. 2006. Topographia, B. Giourdas Publishers.
[7] Hatzopoulos John N., Stilianos Karafillis, Dimitra Gkitakou, 2005. Digital Elevation Data and the Use of ArcHydro to Locate Places for Creation of Small Dams in the North East part of the Greek Island of Naxos. Proceedings, 9th International Conference of Environmental Science and Technology, 1 - 3 September 2005, Phodos Greece.
[8] Jennings, S.B., N. Brown, and D. Sheil. 1999. Assessing forest canopies and understory illumination: canopy closure, canopy cover and other measures. *Forestry* 72(1): 59-73.
[9] Karafillis S., Gkitakou Dimitra, 2004, ArcHydro hydrologic model application in North Eastern part of Naxos island and utilisation of data to locate places for small dam creation. Senior Project, Laboratory o Remote Sensing and Gis, University of Aegean, Department of Environmental Studies.
[10] Lim, K., and P. Treitz, 2004. Estimation of aboveground forest biomass from airborne discrete return laser scanner data using canopy-based quantile estimators, *Scandinavian Journal of Forest Research,* 19:558-570.
[11] Pappi Eugenie, 2003. Planning for the development of North East part of the Greek island of Naxos using GIS with emphasis on hiking trails for tourists. Master thesis on Policy and Management post graduate program, University of Aegean, Department of Environmental Studies.
[12] http://cswgcin.nbii.gov/ecoregion/forthood/
[13] http://www.tsarp.org/viewmaps.html
[14] http://www.cast.uark.edu/cast/geostor/
[15] http://atlas.lsu.edu/lidar/
[16] http://seamless.usgs.gov/
[17] http://www.csc.noaa.gov/crs/tcm/missions.html
[18] http://rocky2.ess.washington.edu/data/raster/lidar/index.htm
[19] Federation of Greek Climbers 1983, Instructions for planning trails in Europe.
[20] The Florida Recreational Trails Council 1998 “Florida Greenway and Trail system design guidelines for unpaved and padding trails”