İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

INTEGRATION OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS IN ARCHAEOLOGICAL APPLICATIONS

M.Sc. Thesis by
Cihan UYSAL, Eng.

Department : Geodesy & Photogrammetry Engineering

Programme : Geomatics Engineering

OCTOBER 2008

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Date of submission : **17 September 2008**
Date of defence examination: **21 October 2008**

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OCTOBER 2008

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

ARKEOLOJİK UYGULAMALARDA UZAKTAN ALGILAMA VE COĞRAFİ BİLGİ SİSTEMİ ENTEGRASYONU

YÜKSEK LİSANS TEZİ

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Tezin Enstitüye Verildiği Tarih : 17 Eylül 2008

Tezin Savunulduğu Tarih : 21 Ekim 2008

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EKİM 2008

FOREWORD

I'm grateful to Prof. Dr. Derya Maktav and Prof. Dr. James Crow for his supports and instructions during preparation of my master thesis and also thankful to my family providing all kind of needs during my education. This work is supported by ITU Institute of Science and Technology.

October 2008 Cihan UYSAL

Geodesy & Photogrammetry Engineering

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ABBREVIATIONS

SRTM	**:** Shuttle Radar Topography Mission
DEM	**:** Digital Elevation Model
DTM	**:** Digital Terrain Model
GIS	**:** Global Positioning System
SAR	**:** Synthetic Aperture Radar
HRS	**:** High Resolution Stereoscopic
HRG	**:** High Resolution Geometric
VHR	**:** Very High Resolution
TIN	**:** Triangular Irregular Network
GPS	**:** Global Positioning System
FOV	**:** Field of View
PALSAR	**:** Phased Array type L-band Synthetic Aperture Radar
AVNIR	**:** Advanced Visible and Near Infrared Radiometer
PRISM	**:** Panchromatic Remote-sensing Instrument for Stereo Mapping
ALOS	**:** Advanced Land Observing Satellite
TM	**:** Thematic Mapper
NIR	**:** Near Infrared
UV	**:** Ultraviolet

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INTEGRATION OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS IN ARCHAEOLOGICAL APPLICATIONS

ABSTRACT

Recent improvements at satellite technologies and information systems has caused the frequently usage of remote sensing and integration of geographic information system. Especially, advances spatial resolution of satellite sensors, remote sensing technology has been used archaeological applications, too. In this study, Kurşunlugerme aqueduct, has been the important part water supply system at the time of Roman, Byzantine and Otoman Empires, and its environment has been chosen. The three dimensional model, which can get by overlaping satellite images onto regional digital terrain models, can provide the terrain topography to demonstrate. Vital analyses and comments will be made by adding GPS measurements at archaeological structures at study area. Moreover, in this study, digital terrain models can verify and compare by 1/25000 topographic maps, SRTM data, ALOS/PRISM stereo satellite images. For getting these results, a simple geographic information system will be used. By this system the results which will get by determining, analysing local water supply systems main lines, by usage of satellite data and terrain measurements, will be useful to gain national cultural heritage to the society.

ARKEOLOJİK UYGULAMALARDA UZAKTAN ALGILAMA VE COĞRAFİ BİLGİ SİSTEMİ ENTEGRASYONU

ÖZET

Günümüzdeki uydu teknolojileri ve bilgi sistemlerindeki son gelişmeler, uzaktan algılama ve coğrafi bilgi sistemi entegrasyonunun birçok alanda daha yoğun bir biçimde kullanılmasına olanak sağlamıştır. Özellikle de uydu algılayıcılarının mekansal çözünürlüğünün her geçen gün artmasıyla birlikte, uzaktan algılama teknolojisi, arkeolojik çalışmalarda da kullanılmaya başlamıştır. Bu çalışmada, Roma, Bizans ve Osmanlı dönemlerinde İstanbul'a su sağlayan su ikmal sistemlerinin önemli bir parçası olan Kurşunlugerme su kemeri ve çevresi çalışma alanı olarak seçilmiştir. Bölgenin dijital arazi modellerine çeşitli uydu görüntülerinin giydirilmesiyle elde edilecek üç boyutlu model ile arazi topoğrafyasının görselleştirilmesi sağlanacaktır. Bölgedeki arkeolojik yapıtlarla ilgili GPS ölçmeleri sonucu elde edilecek değerler bu model üzerine eklenerek gerekli analiz ve yorumlar yapılacaktır. Ayrıca bu çalışmada dijital arazi modelleri 1/25000 topoğrafik paftalardan, SRTM verilerinden, ALOS/PRISM stereo uydu görüntülerinden elde edilip doğrulukları karşılaştırılacaktır. Tüm bu sonuçlar basit bir coğrafi bilgi sistemi içerisinde sunulacaktır. Böyle bir sistem yardımıyla, uydu verileri ve yersel ölçmeler birlikte kullanılarak lokal su ikmal sistemlerine ait hatların belirlenmesi, analizi ve yorumlanmasıyla elde edilecek sonuçların, ülkemizin kültürel miraslarının topluma kazandırılması açısından yararlı olabileceği planlanmaktadır.

1. INTRODUCTION

Turkey has a remarkable strategical and geographical location that being influenced by many empires during history. Therefore, Turkey has a rich cultural inheritance. Istanbul in particular has a unique importance. There are many works of art that remained from Rome , Byzantine and Ottoman Empire in Istanbul. Aqueducts which brought water to towns and were main structures of water supplying systems can be shown as an example of that kind of arts. A system that provided water for Istanbul in ancient time, lies till 250-300 km west of city. Although there are many of aqueducts, most of them are damaged or destroyed by some causes. Moreover, some difficulties were appeared while revealing this aqueduct in detail because of topography and searching large area. There are some uncertainty about route of aqueduct in some areas. Classic terrestrial methods and archaeological methods are used for this work. In addition, advanced satellite technology with developed spatial resolution encourage users to manage archaeological work by using remote sensing technology. Moreover, remote sensing with synoptic visual ability provides working in large area and gives good results.

Kurşunlugerme province, aqueduct and its neighbours was chosen as working area. First, the route of aqueduct is determined by GPS measurements in area. Satellite images are also being used during determination and analyses. Correct analyses can be made by using 3D models which formed as a result of overlaying satellite images into digital terrain models. In this project the accuracy of digital terrain models will be compared. For this purpose, digital elevation models will be formed by using elevation data from 1/25000 maps, SRTM data and PRISM stereo satellite data and accuracy will be evaluated. So geographic information system is established by using 3D models with digital elevation models, satellite images and GPS measurements.

2. FUNDAMENTALS OF ARCHAEOLOGY

2.1 Definition of Archaeology

Archaeology is partly the discovery of treasures of the past, partly the meticulous work of the scientific analyst, partly the exercise of the creative imagination. It is toiling in the sun on an excavation in the deserts of Iraq, it is working with living Inuit in the snows of Alaska. It is diving down to Spanish wrecks off the coast of Florida, and it is investigating the sewers of Roman York. But it is also the painstaking task of interpretation so that we come to understand what these things mean for the human story. And it is the conservation of the world's cultural heritage against looting and against careless destruction. Archaeology is the "past tense of cultural anthropology." Whereas cultural anthropologists will often base their conclusions on the experience of actually living within contemporary communities, archaeologists study past societies primarily through their material remains the buildings, tools and other artifacts that constitute what is known as the material culture left over from former societies (Renfrew and Bahn, 2000).

The objects that archaeologists discover, on the other hand, tell us nothing directly in themselves. It is we today who have to make sense of these things. In this respect the practice of archaeology is rather like that of the scientist. The scientist collects data (evidence), conducts experiments, formulates a hypothesis (a proposition to account for the data), tests the hypothesis against more data, and then in conclusion devises a model (a description that seems best to summarize the pattern observed in the data). The archaeologist has to develop a picture of past, just as the scientist has to develop a coherent view of the natural world. It is not found ready made (Renfrew and Bahn, 2000).

As with most academic disciplines, there are a very large number of archaeological sub-disciplines characterised by a specific method or type of material (e.g. lithic analysis, music, archaeobotany), geographical or chronological focus (e.g. Near

Eastern archaeology, Medieval archaeology), other thematic concern (e.g. maritime archaeology, landscape archaeology, battlefield archaeology), or a specific archaeological culture or civilisation (e.g. Egyptology) [1].

In generally, archaeology includes various of classifications that changes according to time periods and characteristic of civilization during that time periods such as prehistorical and classical archaeology. Classical archaeology consists of period of Hellenic and Rome civilizations that called archaic age. Prehistorical archaeology aims to investigate cultural, economical and technological development of humanity from the beginnig of life until founding of literary [2].

2.2 History of Archaeology

In the broadest sense, just as archaeology is an aspect of antropology, so too is it a part of history, where we mean the whole history of humankind from its beginnings over 3 million years ago. Indeed for more than 99 percent of that huge span of time archaeology, the study of past material culture, is the only significant source of information, if one sets aside physical anthropology, which focuses on our biological rather than cultural progress. Conventional historical sources begin only with the introduction of written records around 3000 BC in Western Asia, and much later in most other parts of the world (not until AD 1788 in Australia, for example). A commonly drawn distinction is between prehistory, the period before written records, and history in the narrow sense, meaning the study of the past using written evidence. In some countries, “prehistory” is now considered a patronizing and derogatory term which implies that written texts are more valuable than oral histories, and which classifies their cultures as inferior until the arrival of western ways of recording information. To archaeology, however, which studies all cultures and periods, whether with or without writing, the distinction between history and prehistory is a convenient dividing linet hat simply recognizes the importances of written word in the modern world, but in no way denigrates the useful information contained in oral histories (Renfrew and Bahn, 2000).

The history of archaeology, then, is a history of new ideas, methods and discoverios. Modern archaeology took root in the 19th century with the acceptance of three key concepts: the great antiquity of humanity, Darwins’s principle of evolution, and the Three Age System for ordering material culture. Many of the early civilizations, especially in the old world, had been discovered by the 1880s, and some of their ancient scripts deciphered. This was followed by a long phase of consolidation of improvements in fieldwork and excavation and the establishment of regional chronologies (Renfrew and Bahn, 2000).

After World War II the pace of change in the discipline quickened. New ecological approaches sought to help us understand human adaptation to the environment. New scientific techniques introduced among other things reliable means of dating the prehistoric past. Spurred on by these developments, the new archaeology of the 1960s and 1970s turned to questions not just of what happened when, but why they happened, in an attempt to explain processes of change. Meanwhile, Pioneer fieldworkers studying whole regions opened up a truly world archaeology in time and space in time back from the present to the earliest toolmakers, and in space across all the world's continents. More recently a diversity of theoretical approaches, often grouped under the label postprocessual, highlighted the variety of possible interpretations and the sensitivity of their politicial implications (Renfrew and Bahn, 2000).

2.3 Excavation

Excavation retains its central role in fieldwork because it yields the most reliable evidence for the two main kinds of information archaeologists are interested in: human activities at a particular period in the past; and changes in those activities from period to period. Very broadly we can say that contemporary activities take place horizontally in space, wheras changes in those activities occur vertically through time. It is this distinction between horizontal slices of time and vertical sequences through time that forms the basis of most excavation methodology. Despite the growing importance of survey, the only way to check the reliability of surface data, confirm the accuracy of the remote sensing techniques, and actually see what remains of these sites is to excavate them. Furthermore, survey can tell us a little about a large area, but only excavation can tell us a great deal about a relatively small area (Renfrew and Bahn, 2000).

In the 18th century more adventurous researchers initiated excavation of some of the most prominent sites. Pompeii in Italy was one of the first of these, with its striking Roman finds, although proper excavation did not begin there until the 19th century.

And in 1765, at the Huaca de Tantalluc on the coast of Peru, a mound was excavated and an offering was discovered in a hollow; the mound's stratigraphy was well described (Renfrew and Bahn, 2000).

2.4 Surface Survey

The simplest way to gain some idea of a site's extent and layout is through a site surface archaeology by studying the distribution of surviving features, and recording and possibly collecting artifacts from the surface. Surface survey has a vital place in archaeological work, and one that continues to grow in importance. In modern projects, however, it is usually supplemented by reconnaissance from the air, one of the most important advances made by archaeology this century. In fact, the availability of air photographs can be an important factor in selecting and delineating an area for surface survey. Until the present century, individual sites were the main focus of archaeological attention, and the only remote sensing devices used were a pair of eyes and a stick. The developments of aerial photography and reconnaissance techniques have shown archaeologists that the entire landscape is of interest, while geophysical and geochemical methods have revolutionized our ability to detect what lies hidden beneath the soil (Renfrew and Bahn, 2000).

Today archaeologists study whole regions, often employing sampling techniques to bring ground reconnaissance (surface survey) within the scope of individual research teams. Having located sites within those regions, and mapped them using aerial reconnaissance techniques and now GIS, archaeologists can then turn to a whole battery of remote sensing site survey devices able to detect buried features without excavation. The geophysical methods almost all involve either passing energy into the ground and locating buried features from their effect on that energy or measuring the intensity of the earth's magnetic field. In either case, they depend on contrast between the buried features and their surroundings. Many of the techniques are costly in both equipment and time, but they are often cheaper and certainly less destructive than random test pits or trial trenches. They allow archaeologiest to be more selective in deciding which parts of a site, if any, should be fully excavated (Renfrew and Bahn, 2000).

3. FUNDAMENTALS OF REMOTE SENSING (RS) AND GIS

3.1 Fundamentals of Remote Sensing (RS)

Remote sensing can be defined as the acquisition and recording of information about an object without being in direct contact with that object (Gibson, 2000).

In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest. This is exemplified by the use of imaging systems where the following seven elements are involved (Figure 3. 1). These seven elements comprise the remote sensing process from beginning to end. Note, however that remote sensing also involves the sensing of emitted energy and the use of non-imaging sensors.

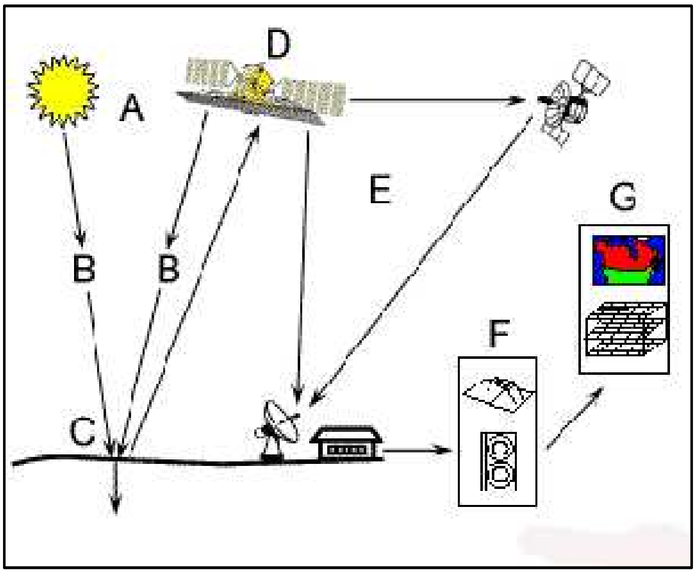

Figure 3. 1: Elements of Remote Sensing.

3.1.1 Basic Elements of RS

A. Energy source or ıllumination – the first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.

B. Radiation and the atmosphere – as the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.

C. Interaction with the target - once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.

D. Recording of energy by the sensor - after the energy has been scattered by, or emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record the electromagnetic radiation.

E. Transmission, reception, and processing - the energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).

F. Interpretation and analysis - the processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.

G. Application - the final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem [7].

3.1.2 Electromagnetic Radiation

The first requirement for remote sensing is to have an energy source to illuminate the target (unless the sensed energy is being emitted by the target). This energy is in the form of electromagnetic radiation. All electromagnetic radiation has fundamental properties and behaves in predictable ways according to the basics of wave theory. Electromagnetic radiation consists of an electrical field(E) which varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field (M) oriented at right angles to the electrical field (Figure 3. 2). Both these fields travel at the speed of light (c) [7].

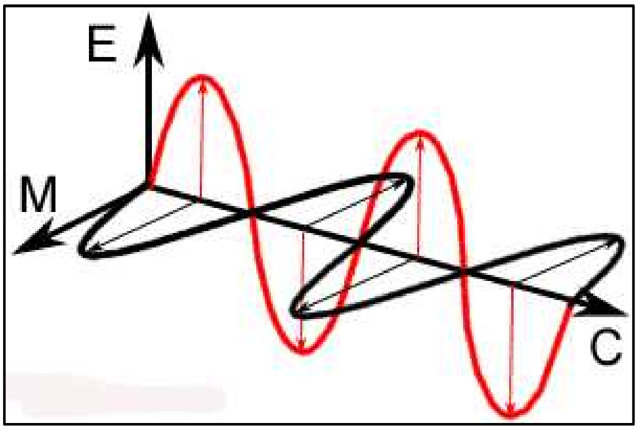

Figure 3. 2: Characteristics of electromagnetic radiation.

Two characteristics of electromagnetic radiation are particularly important for understanding remote sensing. These are the wavelength and frequency (Figure 3. 3).

$$c = \lambda \nu$$

where:

λ = wavelength (m)
ν = frequency (cycles per second, Hz)
c = speed of light (3×10^8 m/s)

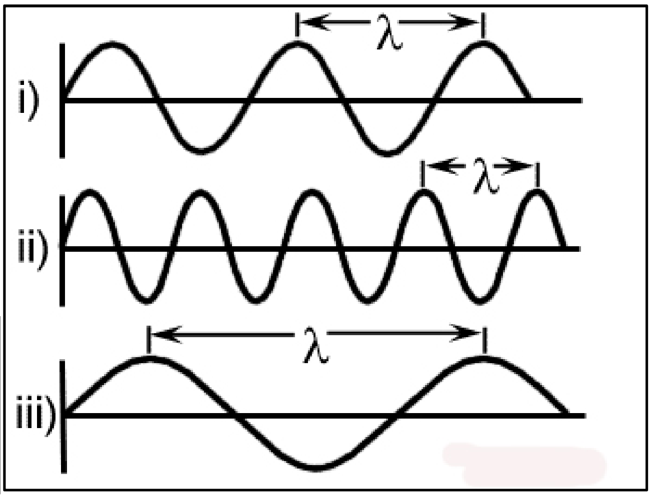

Figure 3. 3: Wavelength and frequency.

Therefore, the two are inversely related to each other. The shorter the wavelength, the higher the frequency. The longer the wavelength, the lower the frequency. Understanding the characteristics of electromagnetic radiation in terms of their wavelength and frequency is crucial to understanding the information to be extracted from remote sensing data [7].

3.1.3 Electromagnetic Spectrum

The electromagnetic spectrum ranges from the shorter wavelengths (including gamma and (x-rays) to the longer wavelengths (including microwaves and broadcast radio waves). There are several regions of the electromagnetic spectrum which are useful for remote sensing (Figure 3. 4).

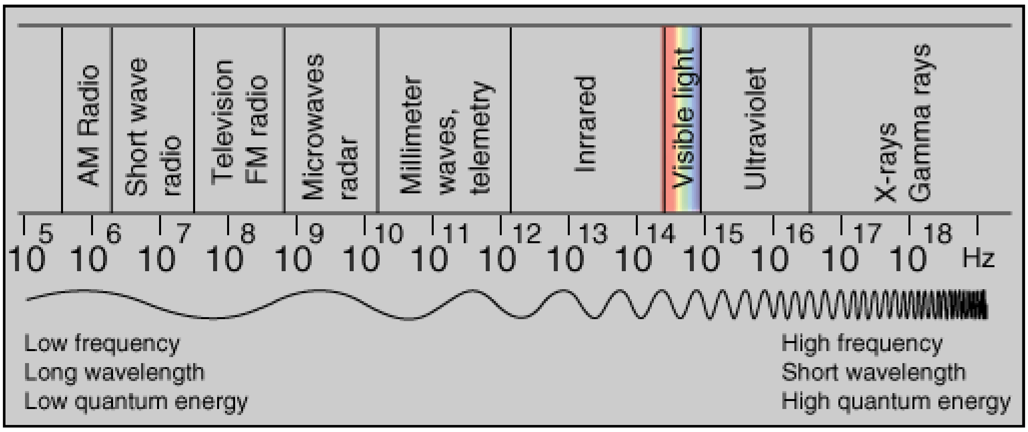

Figure 3.4: Electromagnetic spectrum.

For most purposes, the ultraviolet or UV portion of the spectrum has the shortest wavelengths which are practical for remotesensing. This radiation is just beyond the violet portion of the visible wavelengths, hence its name. Some Earth surface materials, primarily rocks and minerals, fluoresce or emit visible light when illuminated by UV radiation.

The light which our eyes - our "remote sensors" - can detect is part of the visible spectrum. It is important to recognize how small the visible portion is relative to the rest of the spectrum. There is a lot of radiation around us which is "invisible" to our eyes, but can be detected by other remote sensing instruments and used to our advantage. The visible wavelengths cover a range from approximately 0.4 to 0.7 µm. The longest visible wavelength is red and the shortest is violet. Blue, green, and red are the primary colours or wavelengths of the visible spectrum. They are defined as such because no single primary colour can be created from the other two, but all other colours can be formed by combining blue, green, and red in various proportions. Although we see sunlight as a uniform or homogeneous colour, it is actually composed of various wavelengths of radiation in primarily the ultraviolet, visible and infrared portions of the spectrum. The visible portion of this radiation can be shown in its component colours when sunlight is passed through a prism, which bends the light in differing amounts according to wavelength. The next portion of the spectrum of interest is the infrared (IR) region which covers the wavelength range from approximately 0.7 μm to 100 μm - more than 100 times as wide as the visible portion! The infrared region can be divided into two categories based on their radiation properties - the reflected IR, and the emitted or thermal IR. Radiation in the

reflected IR region is used for remote sensing purposes in ways very similar to radiation in the visible portion. The reflected IR covers wavelengths from approximately 0.7 μm to 3.0 μm. The thermal IR region is quite different than the visible and reflected IR portions, as this energy is essentially the radiation that is emitted from the Earth's surface in the form of heat. The thermal IR covers wavelengths from approximately 3.0 μm to 100 μm. The portion of the spectrum of more recent interest to remote sensing is the microwave region from about 1 mm to 1 m. This covers the longest wavelengths used for remote sensing. The shorter wavelengths have properties similar to the thermal infrared region while the longer wavelengths approach the wavelengths used for radio broadcasts.

3.1.4 Interactions with the Atmosphere

All radiation used for remote sensing must pass through the earth's atmosphere. If the sensor is carried by a low flying aircraft, effects of the atmosphere upon image quality may be negligible. In contrast, energy that reaches sensors carried by earth satellites must pass through the entire depth of the earth's atmosphere. Under these conditions, atmospheric effects may have substantial impact upon the quality of images and data that the sensors generate. Therefore, the practice of remote sensing requires knowledge of interactions of electromagnetic energy with the atmosphere (Campbell, 2002).

Scattering occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path. How much scattering takes place depends on several factors including the wavelength of the radiation, the abundance of particles or gases, and the distance the radiation travels through the atmosphere. There are three types of scattering which take place. Rayleigh scattering occurs when particles are very small compared to the wavelength of the radiation. These could be particles such as small specks of dust or nitrogen and oxygen molecules. Rayleigh scattering causes shorter wavelengths of energy to be scattered much more than longer wavelengths. Rayleigh scattering is the dominant scattering mechanism in the upper atmosphere. The fact that the sky appears "blue" during the day is because of this phenomenon. As sunlight passes through the atmosphere, the shorter wavelengths (i.e. blue) of the visible spectrum are scattered more than the other (longer) visible wavelengths. At sunrise and sunset the light has to travel farther through the atmosphere than at midday and the scattering of the shorter wavelengths is more complete; this leaves a greater proportion of the longer wavelengths to penetrate the atmosphere.

Mie scattering occurs when the particles are just about the same size as the wavelength of the radiation. Dust, pollen, smoke and water vapour are common causes of Mie scattering which tends to affect longer wavelengths than those affected by Rayleigh scattering. Mie scattering occurs mostly in the lower portions of the atmosphere where larger particles are more abundant, and dominates when cloud conditions are overcast.

The final scattering mechanism of importance is called nonselective scattering. This occurs when the particles are much larger than the wavelength of the radiation. Water droplets and large dust particles can cause this type of scattering. Nonselective scattering gets its name from the fact that all wavelengths are scattered about equally. This type of scattering causes fog and clouds to appear white to our eyes because blue, green, and red light are all scattered in approximately equal quantities (blue+green+red light = white light) [7].

Absorption is the other main mechanism at work when electromagnetic radiation interacts with the atmosphere. In contrast to scattering, this phenomenon causes molecules in the atmosphere to absorb energy at various wavelengths. Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents which absorb radiation. Ozone serves to absorb the harmful (to most living things) ultraviolet radiation from the sun. Without this protective layer in the atmosphere our skin would burn when exposed to sunlight [7].

3.1.5 Radiation - Target Interactions

Radiation that is not absorbed or scattered in the atmosphere can reach and interact with the Earth's surface. There are three forms of interaction that can take place when energy strikes, or is incident (I) upon the surface. These are: absorption (A); transmission (T); and reflection (R) (Figure 3. 5). The total incident energy will interact with the surface in one or more of these three ways. The proportions of each will depend on the wavelength of the energy and the material and condition of the feature.

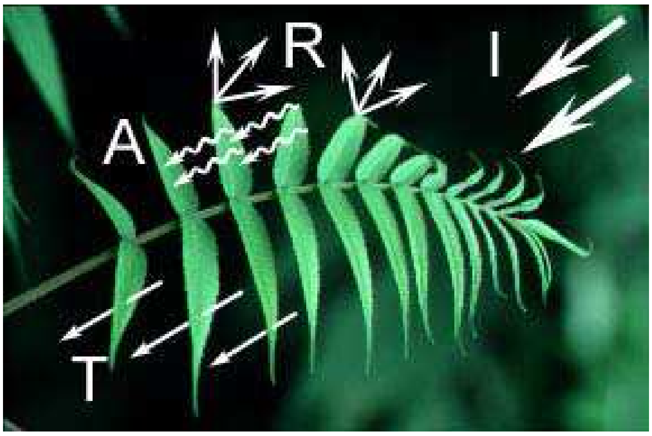

Figure 3. 5: Reflection of leaf.

Absorption (A) occurs when radiation (energy) is absorbed into the target while transmission (T) occurs when radiation passes through a target. Reflection (R) occurs when radiation "bounces" off the target and is redirected. In remote sensing, we are most interested in measuring the radiation reflected from targets. We refer to two types of reflection, which represent the two extreme ends of the way in which energy is reflected from a target: specular reflection and diffuse reflection. When a surface is smooth we get specular or mirror-like reflection where all (or almost all) of the energy is directed away from the surface in a single direction. Diffuse reflection occurs when the surface is rough and the energy is reflected almost uniformly in all directions. Most earth surface features lie somewhere between perfectly specular or perfectly diffuse reflectors. Whether a particular target reflects specularly or diffusely, or somewhere in between, depends on the surface roughness of the feature in comparison to the wavelength of the incoming radiation. If the wavelengths are much smaller than the surface variations or the particle sizes that make up the surface, diffuse reflection will dominate. For example, finegrained sand would appear fairly smooth to long wavelength microwaves but would appear quite rough to the visible wavelengths. There are some examples of targets at the Earth's surface and how energy at the visible and infrared wavelengths interacts with them.

Leaves: A chemical compound in leaves called chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects gren wavelengths. Leaves appear "greenest" to us in the summer, when chlorophyll content is at its maximum. In autumn, there is less chlorophyll in the leaves, so there is less absorption and proportionately more reflection of the red wavelengths, making the leaves appear red or yellow (yellow is a combination of red and green wavelengths). The internal structure of healthy leaves act as excellent diffuse reflectors of near-infrared wavelengths. If our eyes were sensitive to near-infrared, trees would appear extremely bright to us at these wavelengths. In fact, measuring and monitoring the near-IR reflectance is one way that scientists can determine how healthy (or unhealthy) vegetation may be (Figure 3. 6).

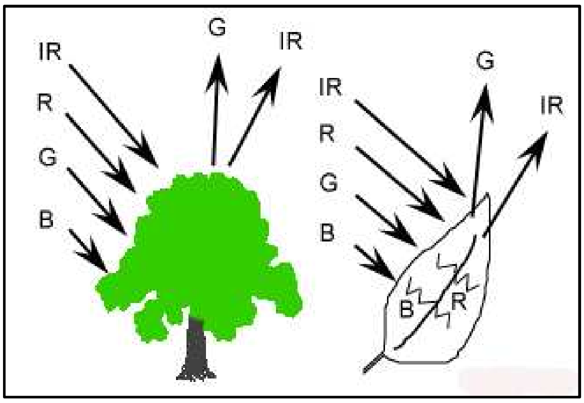

Figure 3. 6: Reflection of vegetation.

Water: Longer wavelength visible and near infrared radiation is absorbed more by water than shorter visible wavelengths. Thus water typically looks blue or blue-green due to stronger reflectance at these shorter wavelengths, and darker if viewed at red or near infrared wavelengths (Figure 3. 7). If there is suspended sediment present in the upper layers of the water body, then this will allow better reflectivity and a brighter appearance of the water. The apparent colour of the water will show a slight shift to longer wavelengths. Suspended sediment (S) can be easily confused with shallow (but clear) water, since these two phenomena appear very similar. Chlorophyll in algae absorbs more of the blue wavelengths and reflects the green, making the water appear more green in colour when algae is present. The topography of the water surface (rough, smooth, floating materials, etc.) can also lead to complications for water-related interpretation due to potential problems of specular reflection and other influences on colour and brightness [7].

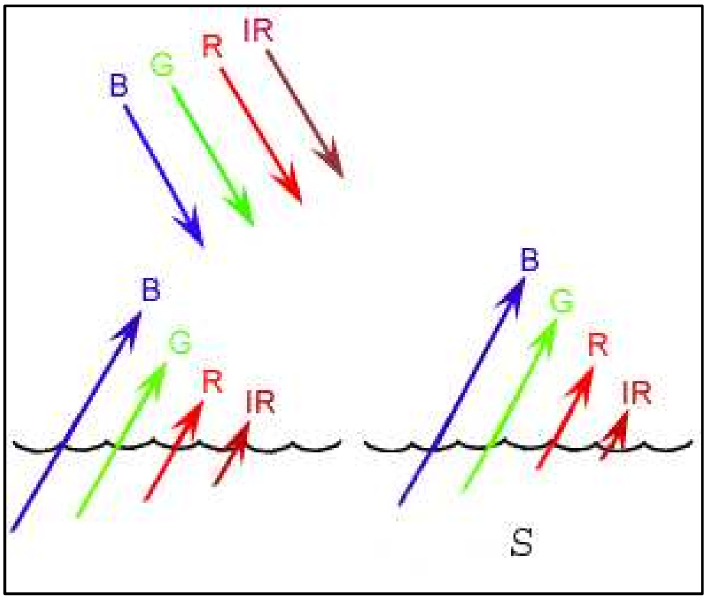

Figure 3. 7: Reflection of water.

When solar radiation hits a target surface, it may be transmitted, absorbed or reflected. Different materials reflect and absorb differently at different wavelengths. The reflectance spectrum of a material is a plot of the fraction of radiation reflected as a function of the incident wavelength and serves as a unique signature for the material. In principle, a material can be identified from its spectral reflectance signature if the sensing system has sufficient spectral resolution to distinguish its spectrum from those of other materials. This premise provides the basis for multispectral remote sensing. The following graph shows the typical reflectance spectra of five materials: clear water, turbid water, bare soil and two types of vegetation (Figure 3. 8) (Campbell, 2002).

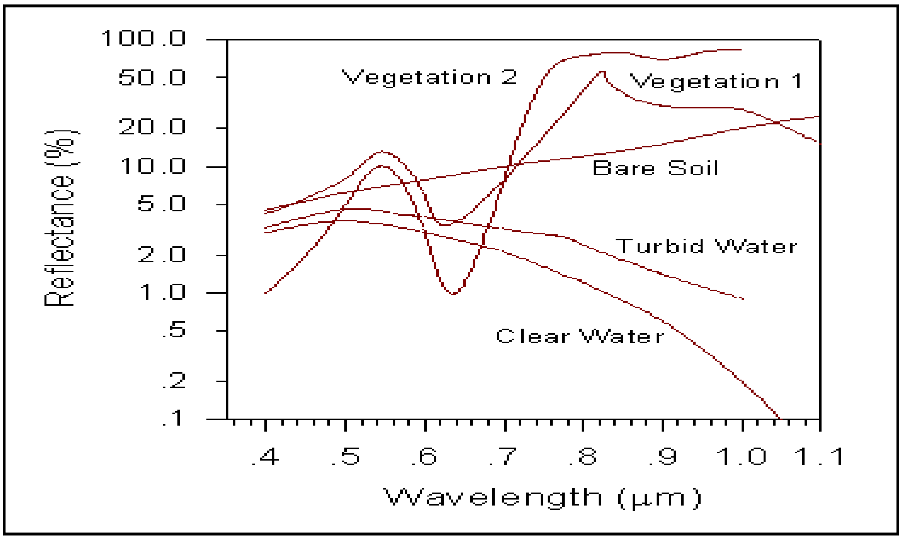

Figure 3. 8: Spectral reflectance of some surface.

Vegetation has a unique spectral signature which enables it to be distinguished readily from other types of land cover in an optical/near-infrared image. The reflectance is low in both the blue and red regions of the spectrum, due to absorption by chlorophyll for photosynthesis. It has a peak at the green region which gives rise to the green colour of vegetation. In the near infrared (NIR) region, the reflectance is much higher than that in the visible band due to the cellular structure in the leaves. Hence, vegetation can be identified by the high NIR but generally low visible reflectances. This property has been used in early reconnaisance missions during war times for "camouflage detection".

The shape of the reflectance spectrum can be used for identification of vegetation type. For example, the reflectance spectra of vegetation 1 and 2 in the above figures can be distinguished although they exhibit the generally characteristics of high NIR but low visible reflectances. Vegetation 1 has higher reflectance in the visible region but lower reflectance in the NIR region. For the same vegetation type, the reflectance spectrum also depends on other factors such as the leaf moisture content and health of the plants [8].

3.1.6 Passive and Active Sensing

There are two basic types of sensors: passive and active sensors. Passive sensors record radiation reflected from the earth's surface (Figure 3. 9). The source of this radiation must come from outside the sensor; in most cases, this is solar energy. Because of this energy requirement, passive solar sensors can only capture data during daylight hours. The Thematic Mapper (TM) sensor system on the Landsat satellite is a passive sensor [9].

Active sensors are different from passive sensors. Unlike passive sensors, active sensors require the energy source to come from within the sensor (Figure 3. 10). For example, a laser-beam remote sensing system is an active sensor that sends out a beam of light with a known wavelength and frequency. This beam of light hits the earth and is reflected back to the sensor, which records the time it took for the beam of light to return [9].

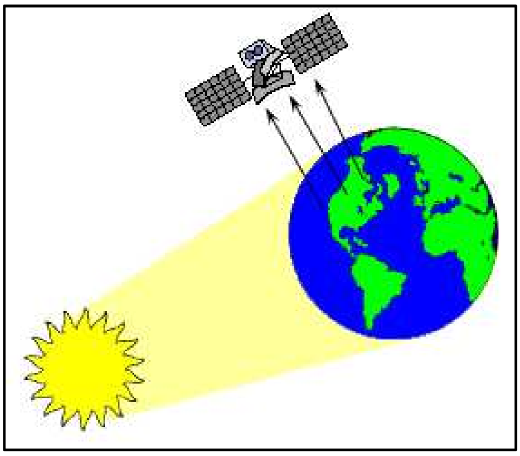

Figure 3.9: Passive sensor.

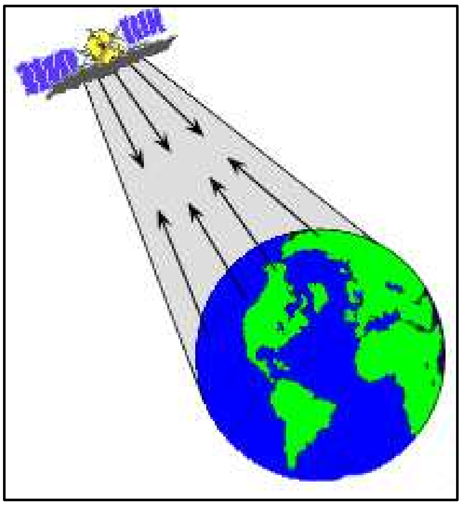

Figure 3.10: Active sensor.

3.1.7 Spatial Resolution

The detail discernible in an image is dependent on the spatial resolution of the sensor and refers to the size of the smallest possible feature that can be detected. Spatial resolution of passive sensors depends primarily on their Instantaneous Field of View (IFOV) (Figure 3. 11). The IFOV is the angular cone of visibility of the sensor (A) and determines the area on the Earth's surface which is "seen" from a given altitude at one particular moment in time (B). The size of the area viewed is determined by multiplying the IFOV by the distance from the ground to the sensor (C). This area on the ground is called the resolution cell and determines a sensor's maximum spatial resolution. For a homogeneous feature to be detected, its size generally has to be equal to or larger than the resolution cell. If the feature is smaller than this, it may not be detectable as the average brightness of all features in that resolution cell will be recorded. However, smaller features may sometimes be detectable if their reflectance dominates within a articular resolution cell allowing sub-pixel or resolution cell detection.

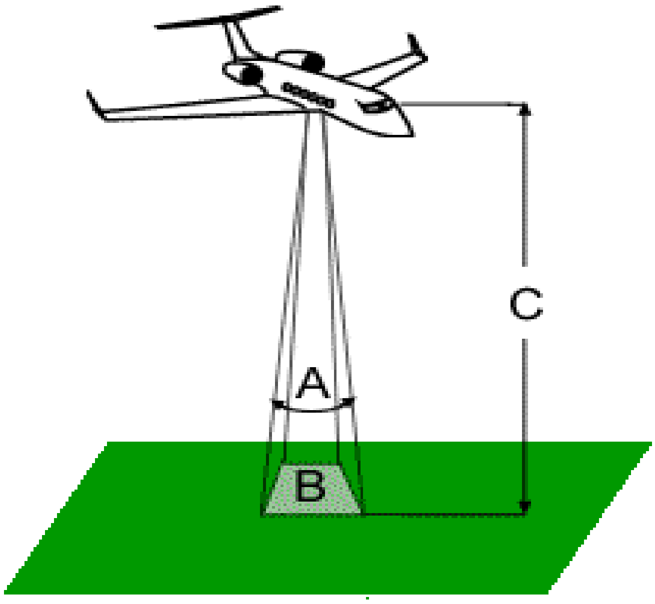

Figure 3.11: Instantaneous Field of View (IFOV).

Most remote sensing images are composed of a matrix of picture elements, or pixels, which are the smallest units of an image. Image pixels are normally square and represent a certain area on an image. It is important to distinguish between pixel size and spatial resolution - they are not interchangeable. If a sensor has a spatial resolution of 20 meters and an image from that sensor is displayed at full resolution, each pixel represents an area of 20m x 20m on the ground. In this case the pixel size and resolution are the same. However, it is possible to display an image with a pixel size different than the resolution. Many posters of satellite images of the Earth have their pixels averaged to represent larger areas, although the original spatial resolution of the sensor that collected the imagery remains the same. Images where only large features are visible are said to have coarse or low resolution (Figure 3. 12). In fine or high resolution images, small objects can be detected (Figure 3. 13). Military sensors for example, are designed to view as much detail as possible, and therefore have very fine resolution. Commercial satellites provide imagery with resolutions varying from a few metres to several kilometres. Generally speaking, the finer the resolution, the less total ground area can be seen[7].

Figure 3.12: Low Resolution.

Figure 3.13: High Resolution.

3.1.8 Spectral Resolution

Different classes of features and details in an image can often be distinguished by comparing their responses over distinct wavelength ranges. Broad classes, such as water and vegetation, can usually be separated using very broad wavelength ranges - the visible and near infrared. Other more specific classes, such as different rock types, may not be easily distinguishable using either of these broad wavelength ranges and would require comparison at much finer wavelength ranges to separate them. Thus, we would require a sensor with higher spectral resolution. Spectral resolution describes the ability of a sensor to define fine wavelength intervals. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band.

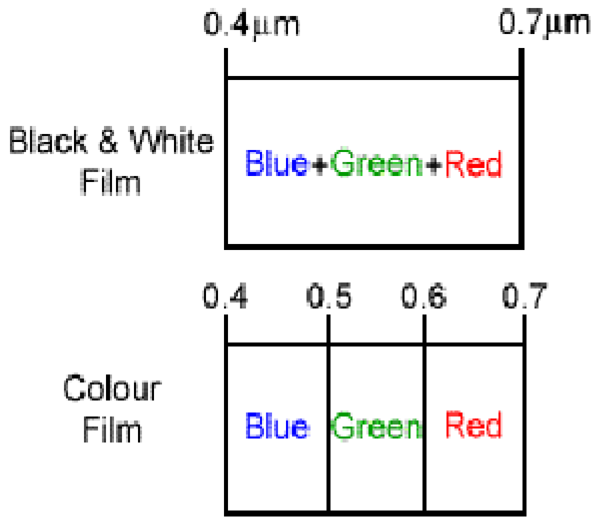

Figure 3.14: Colour and Black & White Film.

Black and white film records wavelengths extending over much, or all of the visible portion of the electromagnetic spectrum (Figure 3. 14) . Its spectral resolution is fairly coarse, as the various wavelengths of the visible spectrum are not individually distinguished and the overall reflectance in the entire visible portion is recorded. Colour film is also sensitive to the reflected energy over the visible portion of the spectrum, but has higher spectral resolution, as it is individually sensitive to the reflected energy at the blue, green, and red wavelengths of the spectrum. Thus, it can represent features of various colours based on their reflectance in each of these distinct wavelength ranges. Many remote sensing systems record energy over several separate wavelength ranges at various spectral resolutions. Advanced multi-spectral sensors called hyperspectral sensors, detect hundreds of very narrow spectral bands throughout the visible, near-infrared, and mid-infrared portions of the electromagnetic spectrum. Their very high spectral resolution facilitates fine discrimination between different targets based on their spectral response in each of the narrow bands[7].

3.1.9 Radiometric Resolution

While the arrangement of pixels describes the spatial structure of an image, the radiometric characteristics describe the actual information content in an image. Every time an image is acquired on film or by a sensor, its sensitivity to the magnitude of the electromagnetic energy determines the radiometric resolution. The radiometric resolution of an imaging system describes its ability to discriminate very slight differences in energy The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy.

Figure 3.15: Different Radiometric Resolution.

Imagery data are represented by positive digital numbers which vary from 0 to (one less than) a selected power of 2. This range corresponds to the number of bits used for coding numbers in binary format. Each bit records an exponent of power 2 (e.g. 1 bit=2^1 =2). The maximum number of brightness levels available depends on the number of bits used in representing the energy recorded. Thus, if a sensor used 8 bits to record the data, there would be 2^8 =256 digital values available, ranging from 0 to 255. However, if only 4 bits were used, then only 2^4=16 values ranging from 0 to 15 would be available. Thus, the radiometric resolution would be much less. Image data are generally displayed in a range of grey tones, with black representing a digital number of 0 and white representing the maximum value (for example, 255 in 8-bit data). By comparing a 2-bit image with an 8-bit image, we can see that there is a large difference in the level of detail discernible depending on their radiometric resolutions [7] (Figure 3. 15).

3.1.10 Temporal Resolution

In addition to spatial, spectral, and radiometric resolution, the concept of temporal resolution is also important to consider in a remote sensing system. The revisit period of a satellite sensor is usually several days. Therefore the absolute temporal resolution of a remote sensing system to image the exact same area at the same viewing angle a second time is equal to this period. However, because of some degree of overlap in the imaging swaths of adjacent orbits for most satellites and the increase in this overlap with increasing latitude, some areas of the Earth tend to be re-imaged more frequently. Also, some satellite systems are able to point their sensors to image the same area between different satellite passes separated by periods from one to five days. Thus, the actual temporal resolution of a sensor depends on a variety of factors, including the satellite/sensor capabilities, the swath overlap, and latitude. The ability to collect imagery of the same area of the Earth's surface at different periods of time is one of the most important elements for applying remote sensing data. Spectral characteristics of features may change over time and these changes can be detected by collecting and comparing multi-temporal imagery. For example, during the growing season, most species of vegetation are in a continual state of change and our ability to monitor those subtle changes using remote sensing is dependent on when and how frequently we collect imagery. By imaging on a continuing basis at different times we are able to monitor the changes that take place on the Earth's surface, whether they are naturally occurring (such as changes in natural vegetation cover or flooding) or induced by humans (such as urban development or deforestation). The time factor in imaging is important when:

-persistent clouds offer limited clear views of the Earth's surface (often in the tropics)

-short-lived phenomena (floods, oil slicks, etc.) need to be imaged

-multi-temporal comparisons are required (e.g. the spread of a forest disease from one year to the next)

-the changing appearance of a feature over time can be used to distinguish it from near similar features (wheat / maize) [7].

3.2 Fundamentals of GIS

GIS is a system of hardware and software used for storage, retrieval, mapping, and analysis of geographic data. Practitioners also regard the total GIS as including the operating personnel and the data that go into the system. Spatial features are stored in a coordinate system (latitude/longitude, state plane, UTM, etc.), which references a particular place on the earth. Descriptive attributes in tabular form are associated with spatial features. Spatial data and associated attributes in the same coordinate system can then be layered together for mapping and analysis. GIS can be used for scientific investigations, resource management, and development planning. GIS differs from CAD and other graphical computer applications in that all spatial data is geographically referenced to a map projection in an earth coordinate system. For the most part, spatial data can be "re-projected" from one coordinate system into another, thus data from various sources can be brought together into a common database and integrated using GIS software. Boundaries of spatial features should "register" or align properly when re-projected into the same coordinate system. Another property of a GIS database is that it has "topology," which defines the spatial relationships between features. The fundamental components of spatial data in a GIS are points, lines (arcs), and polygons. When topological relationships exist, you can perform analyses, such as modeling the flow through connecting lines in a network, combining adjacent polygons that have similar characteristics, and overlaying geographic features [15].

3.2.1 Definition of GIS

Geographical Information System is associated with basic terms, Geography and Information system. The literal interpretation of geography is writing about the Earth. In writing about the Earth, geographers deal with the spatial relationship of land with man. key tool in studying the spatial relationships is the map which is a graphical portrayal of spatial relationships and pherıomena over a small segment of the Earth or the entire Earth. On the other hand, an information system is a chain of operations that consists of from planning the observation to using the observation derived information in some decision making process. A GIS is an information system that is designed to work with data referenced by spatial or geographical coordinates. in other words, a GIS is both a database system with specific capabilities for spatially referenced data as well as a set of operations for working with the data as shown in Fig. 3.16.

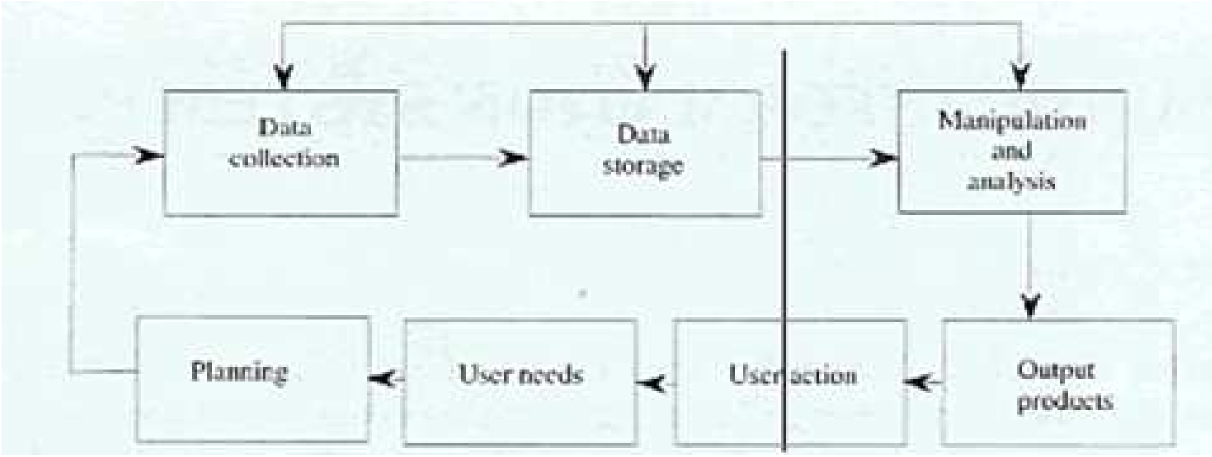

Figure 3.16: Simplified Information System.

Some of the definitions of GIS given in different publications are:

- "A system which uses a spatial database to provide answers to queries of a geographical nature" (Goodchild, 1991).
- "A computer assisted system for the capture, storage, retrieval, analysis and display of spatial data within a particular organization"(Clark, 2001).
- "An organized collection of computer hardware, software, geographical data and personel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information" (ESRI).

  Also the components of GIS can be defined in various ways, but very comprehensively, it can have the that components; computer system (hardware and operating system), software, spatial data, data management and analysis procedures, and personel to operate the GIS.

3.2.2 GIS Data Types

Geographic data consists of spatial data and non-spatial data. The spatial data give information about the geometrical orientation, shape and size of a feature, and its relative position with respect to the position of other features. Spatial data is described by its x and y coordinates. The non-spatial data, also known as attribute data, are information about various attributes like length, area, population, acreage, etc. Normally the spatial and non-spatial data are stored separately in a GIS, and links are established between the two at the time of processing and analysis. The spatial data is normally available in analog form as maps but now the maps are also available directly in digital format. In GIS, both types of the spatial data are handled differently. The non-spatial data describe the attributes of a point, along a line, or in a polygon. In other words they describe what is at a point (e.g., a hospital), along a line (e.g., a canal), or in a polygon (e.g., a forest). The attributes of a soil category may be depth of soil, texture, type of erosion, or permeability. The non-spatial data, mostly available in tabular form, are also converted into digital format for use in GIS.

3.2.3 Data Sources

The data for GIS collected from different sources as satellite imagery, existing maps, aerial photographs and digital orthophotographs, attribute data, survey data and records and other sources. Remote sensing data in the form of satellite imagery is an important element of the organization of any GIS database as it makes possible repetitive coverage of large areas. Satellite imagery can be used as a raster backdrop on vector GIS data. Satellite images can support numerous GIS applications including environmental impact analysis, site evaluation for large facilities, highway planning, development and monitoring of environmental baselines, emergency and disaster response, agriculture and forestry. Satellite images are also useful for urban planning and management. In addition to image analysis, satellite images are used to generate thematic information resulting into thematic maps.

Attribute data for a GIS are mainly tabular data collected by sampling. The tabular data which are tables consisting of rows representing samples and columns representing parameter values can be incorporated into GIS as rational tables. Also some survey data and records about rock types, soil types, elevation, population and other features are collected by the related national agencies of a country and maintained in the form of maps and tables. These data can be incorporated into a GIS (Chandra, Ghosh, 2006) .

4. IMPORTANCE OF REMOTE SENSING AND GIS IN ARCHAEOLOGY

4.1 GIS in Archaeology

The spatial dimension is central to archaeology because it involves all levels of archaeological research, theory, method and practice. The collection, analysis, interpretation and presentation of archaeological data must actively and creatively take into account the spatial dimension. To a certain extent, archaeology can be viewed as a discipline involved in sampling space in order to understand human behaviour. Despite the centrality of space to archaeological theory and practice there have been numerous frustrations and limitations with how archaeologists have been able to collect data about spatial behaviour and the ways in which they can analyze, interpret and present their conclusions. These obstacles derive from theoretical problems in partitioning behavioural and material patterns into arbitrary spatial units, and methodological issues relating to the systematic and concurrent consideration of space, time and form (Allen, Green and Zubrow,1990).

Geographic information systems are essentially spatially referenced databases that allow one to control fort he distribution of form over space and through time. They are more than computerized cartography because they provide for the storage, mathematical manipulation, quick retrieval and flexible display of spatially referenced data (Allen, Green and Zubrow,1990).

Archaeology, as a spatial discipline, has used GIS in a variety of ways. At the simplest level, GIS has found applications as database management for archaeological records, with the added benefit of being able to create instant maps. It has been implemented in cultural resource management contexts, where archaeological site locations are predicted using statistical models based on previously identified site locations. It has also been used to simulate diachronic changes in past landscapes, and as a tool in intra-site analysis [3].

There are a lot of projects which demonstrate the benefits of applying 3D GIS to archaeological and cultural heritage projects by integrating all required types of information into a single system environment. It is also shown, that a 3D GIS serves as an ideal platform for generating web-based 3D geoinformation services (Wüst and Nebiker, 2004).

GIS is a powerful tool for density analysis of selected features or artifact types across a site, or of site types across a region. Visualize patterns and relationships with ArcGlobe, part of the ArcGIS 3D Analyst extension. ArcGlobe provides continuous, multiresolution, interactive viewing of geographic information (Figure 4.1). Like ArcMap, ArcGlobe works with GIS data layers, displaying information from a geodatabase and all supported GIS data formats. ArcGIS 3D Analyst allows you to effectively visualize and analyze surface data. Using ArcGIS 3D Analyst, you can view a surface from multiple viewpoints, query a surface, determine what is visible from a chosen location on a surface, create a realistic perspective image that drapes raster and vector data over a surface, and record or perform three-dimensional navigation [4].

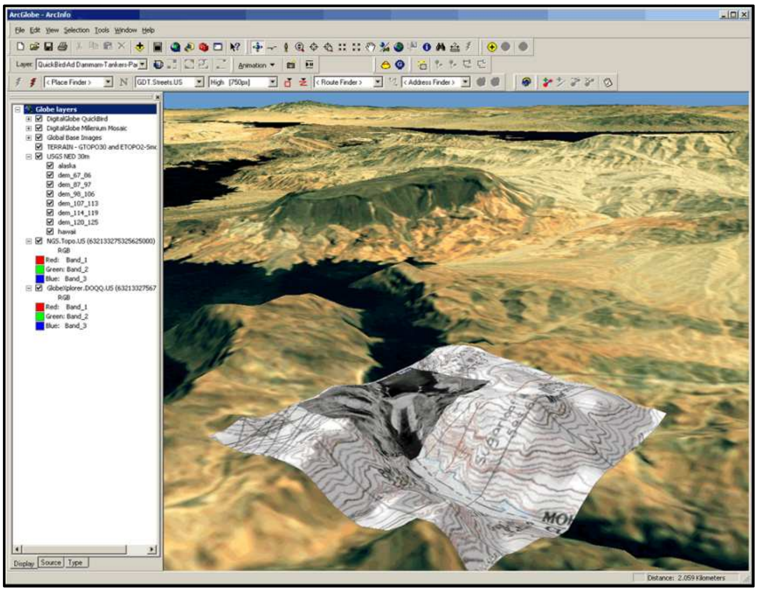

Figure 4.1: Three-dimensional image in ArcGlobe.

Archaeology is a discipline Figure 4.1: that collect and use geospatial data. The field of archaeology in particular is now quite advanced in its use of GIS related technologies (satellite data, GPS units, GIS mapping and spatial analysis) [5].

When I attended “3D Modelling in Archaeology and Cultural Heritage” in Ascona, Switzerland, 9-14 May 2008, I noticed that there were a lot of application about GIS and Archaeology [15]. One of them was contribution of GIS to archaeological research:

- Analysis of spatial disposition of archaeological features.
- Analysis of spatial relations between archaeological features and their cultural and natural surroundings.
- Quantitative and statistical analyses.

While these archaeological analyses predate GIS, they are greatly facilitated by the quantitative, spatial, and computational capabilities of GIS. There are a lot of main applications like visibility , least cost pathways analysis, predictive or locational modelling and 3D building information system.

Predictive or Locational Modelling draws informed conclusions about potential locations of hitherto unknown archaeological sites

- Research tool for archaeologists: Integration of missing sites into reconstructions of cultural history.
- Planning tool for cultural resource managers: Assessment of the probability of a given lot of land (to be developed) to hold archaeological features.

Predictive or Locational Modelling is based on regular patterns of relationships between archaeological sites and environmental variables. There is an example from Grisons, Swiss Alps (Figure 4.2).. Significant factors are slope and elevation.

- red = low probability ($p < 0.3$)
- yellow = medium probability ($0.3 < p < 0.6$)
- green = high probability ($p > 0.6$)

As a result,GIS has become a standard tool for data management and analysis in archaeology.

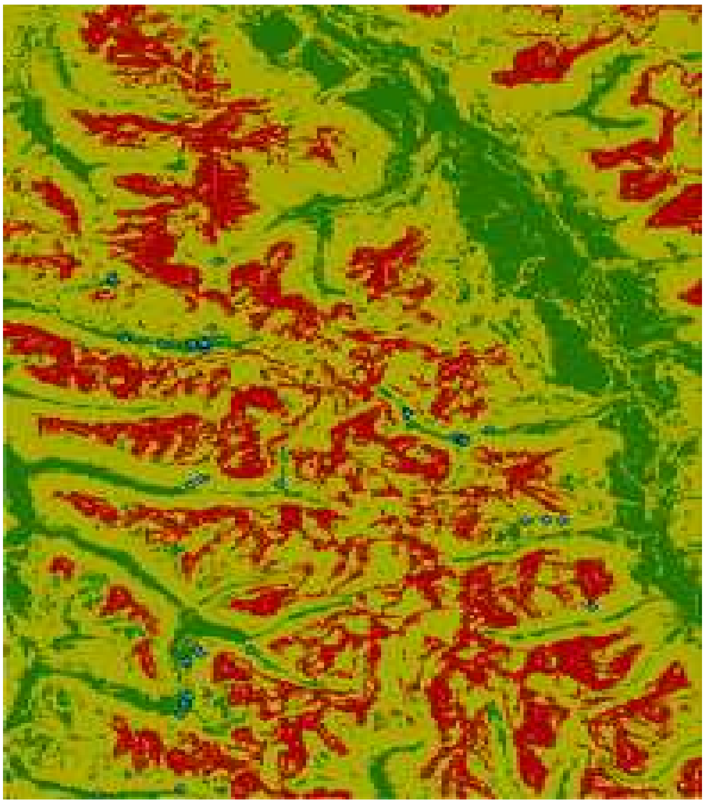

Figure 4.2: Predictive Modelling from Grisons, Swiss Alps.

4.2 Remote Sensing in Archaeology

"Remote sensing is the acquisition of information about an object without touching it" (Jensen, 2000). This broad definition encompasses all types of remote sensing, including sub-surface remote sensing, aerial photography, aerial spectroscopy and satellite remote sensing. Hence, in its broadest sense and in relation to archaeology, remote sensing encompasses methods to discover and map remnants of past civilisations above or below ground level (e.g. crop marks, buried archaeological remains, traces of ancient industrial activity and above ground architectural remnants). Remote sensing is very useful in preparing an intensive survey campaign or directing fieldwork. Viewing archaeological structures from ground level generally does not clearly identify the spatial characteristics of these structures or the relationship to surrounding archaeological sites. In some cases ancient structures are not apparent from ground level but become obvious from a bird's eye view [6].

Satellite remote sensing can provide a variety of useful data for archaeolaogical researches. A variety of sources for such data exist, and while the data can be expensive and require extensive digital image processing, they provide a synoptic view which is not available from aerial photography (De Laet and Paulissen et. al., 2006)

Since the beginning of the 20th century, aerial photography has been used in archaeology primarily to view features on the earth's surface, which are difficult if not impossible to visualise from ground level (Sever, 1995; Vermeulen and Verhoeven, 2004). With the launch of the first Landsat satellite in 1972, satellite remote sensing also became accessible to the archaeological community (Clark et al., 1998). However, due to ground resolution constraints, much of these satellite images do not provide more and probably provide even less information than aerial photography for archaeological purposes. Indeed, even the most recent Landsat ETM^+ images have a resolution of 15 m for the panchromatic band, which is not detailed enough for the identification of most archaeological structures. Therefore, the launch of the first commercial very high-resolution satellite, IKONOS, in 1999 was a major advancement for archaeological research application purposes. This satellite platform provides panchromatic images with 1 m spatial resolution. Fusing the 1 m panchromatic and 4 m multispectral bands, a 1 m false or natural colour image can be generated. Recently, aerial hyperspectral imagery has also been used in archaeology (Emmolo and Franco et. al., 2004). Hyperspectral imagery is characterised by its enormous number of wavebands and (not necessarily) very high spatial resolution defined by the operator (PCI Geomatics, 1998). Until now, very few geoarchaeological studies have applied images with such a high spatial resolution (Changlin and Ning et al., 2004; Emmolo and Franco et al., 2004).

At Hisar, a distinction between archaeological structures and inferred archaeological structures based on the on the Ikonos-2 satellite image is made (Figure 4. 3). Only the main visual structures are indicated. The significance of the inferred structures is not yet clear. Also, colour and shape of these inferred archaeological structures are less characteristic. The identified objects are remnants of a Byzantine and Early Hellenistic defence wall and some pre-Roman house constructions (Waelkens et al., 2000). The perimeter of the inferred defence wall elements that are identified by visual interpretation amounts to 510 m. The remnants of ancient houses cover an area of 3800 m^2 (De Laet and Paulissen et. al., 2006).

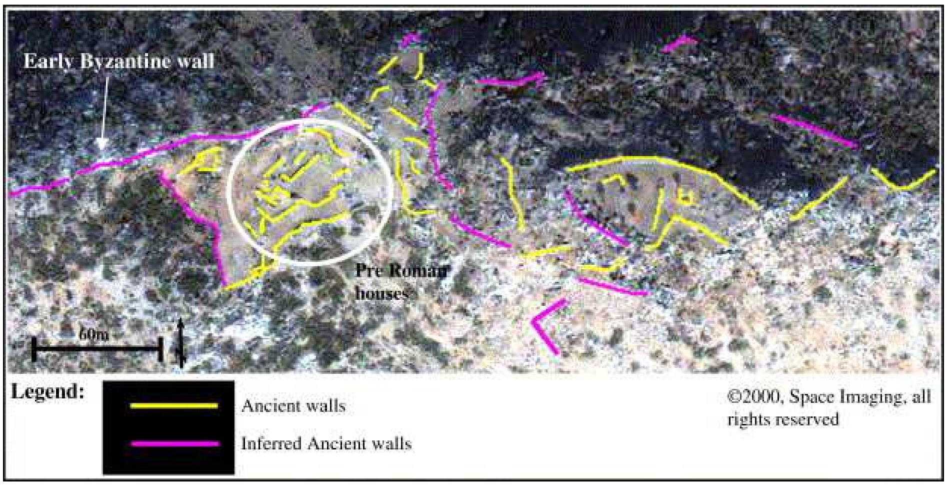

Figure 4.3: Visual interpretation of main archaeological structures on IKONOS-2 imagery.

This is a photo of a Gallo-Roman villa that was discovered by aerial survey in 1979, and is located in an area where Gallo-Roman pottery was located, but the nature and extent of the site was not evident from the ground (Figure 4. 4). This is considered to be a large Roman villa, around 100 m per side, and the outline of individual rooms can be seen. The walls were constructed of cement and stone, and are currently around 60 cm below the current surface. Individual rooms served as workshops, granaries, living quarters, as well as many other uses (Source: GIS and Remote Sensing for Archaeology, Burgundy, France website) [1].

Figure 4.4 : Aerial photo of Gallo-Roman.

Much of human history can be traced through the impacts of human actions upon the environment. The use of remote sensing technology offers the archeologist the opportunity to detect these impacts which are often invisible to the naked eye. This information can be used to address issues in human settlement, environmental interaction, and climate change. Archeologists want to know how ancient people successfully adapted to their environment and what factors may have led to their collapse or disappearance. Remote sensing can be used as a methodological procedure for detecting, inventorying, and prioritizing surface and shallow-depth archeological information in a rapid, accurate, and quantified manner [6].

5. APPLICATIONS

5.1 Study Area

Kurşunlugerme aqueduct and its neighbours was chosen as working area (Figure 5.1). This area is settled near Gümüşpınar village in Çatalca district of İstanbul. It consists of 15 km² area. This aqueduct is one of the magnificent aqueduct of the late Roman and Byzantine water supply system of İstanbul.

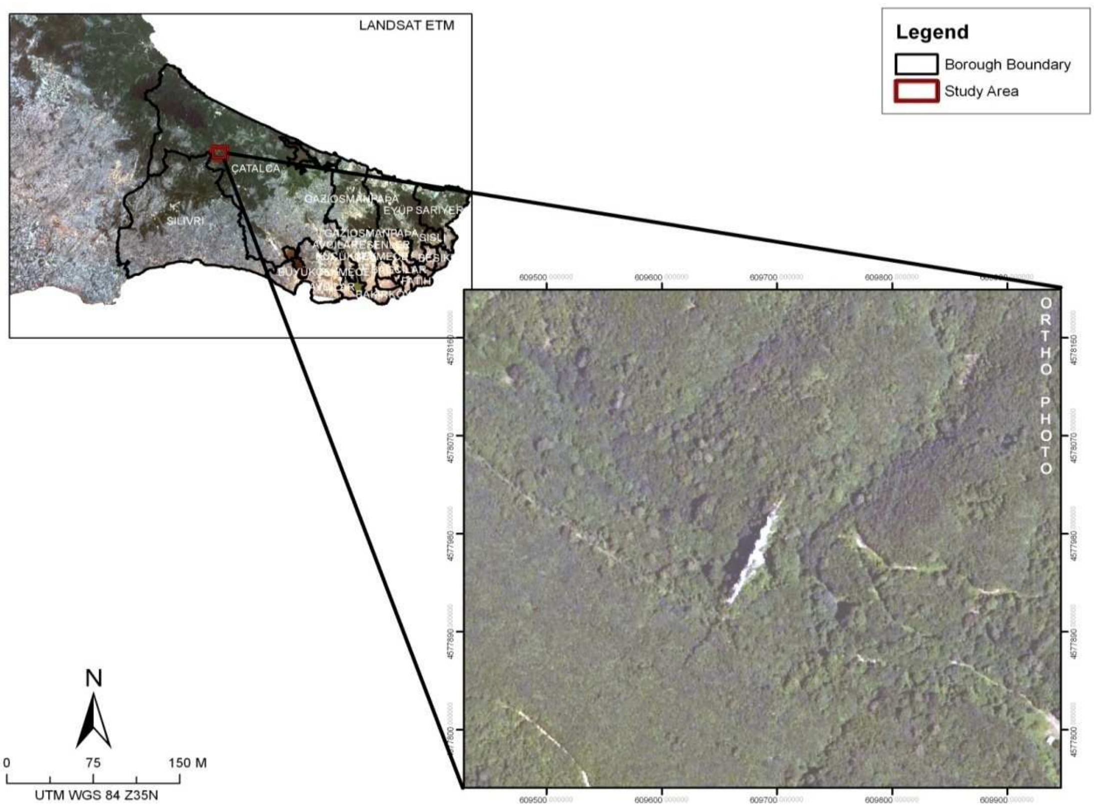

Figure 5.1: Study Area.

5.2 Data Used

At this study, IKONOS pansharpened image (2005), LANDSAT ETM (1987) and orthophoto (2005) are used for visulation, location and overlapping process. To generate DTM, there are three types images: SRTM (3 arcsecond), 1/25000 scaled topographical maps and ALOS Prism stereo image (triplet mode, 2.5 m accuracy). All these data have WGS84 datum and UTM 35N zone projection. Also at this study, Trimble GeoXT handheld GPS is used. It has horizantal accuracy under 1 meter. ArcGIS 9.2 (ArcView), ERDAS 9.1 and PCI Geomatica 10.1 (OrthoEngine module) are used as software.

5.2.1 ALOS

The Advanced Land Observing Satellite (ALOS) developed by the Japan AerospaceExploration Agency (JAXA) was successfully launched on January 24, 2006. The satellite has three sensors i.e., two optical imagers(PRISM and AVNIR-2) and an L-band Synthetic Aperture (PALSAR). The mission objectives of ALOS include cartography, regional observation, and disaster monitoring [10].

The ALOS has three remote-sensing instruments: the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) for digital elevation mapping, the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) for precise land coverage observation, and the Phased Array type L-band Synthetic Aperture Radar (PALSAR) for day-and-night and all-weather land observation (Figure 5.2). In order to utilize fully the data obtained by these sensors, the ALOS was designed with two advanced technologies: the former is the high speed and large capacity mission data handling technology, and the latter is the precision spacecraft position and attitude determination capability. They will be essential to high-resolution remote sensing satellites in the next decade. ALOS have been successfuly launched on an H-IIA launch vehicle from the Tanegashima Space Center, Japan (Table 5.1) [11].

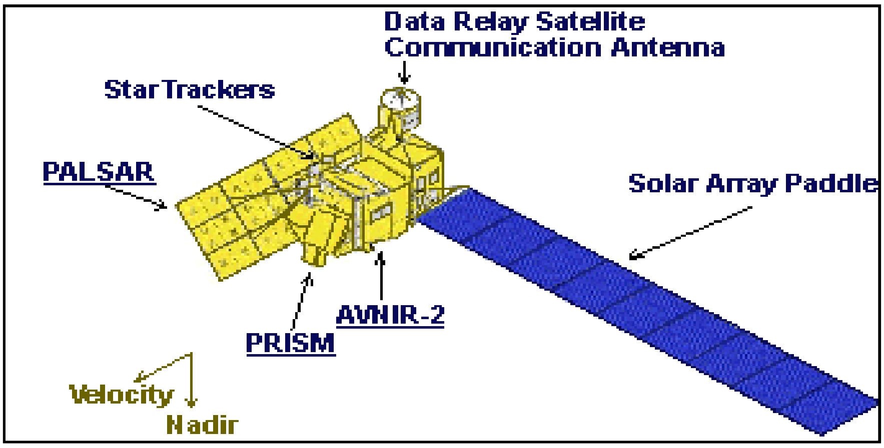

Figure 5. 2: Instruments of ALOS.

Table 5.1: Characteristics of ALOS.

ALOS Characteristics	
Launch Date	Jan. 24, 2006
Launch Vehicle	H-IIA
Launch Site	Tanegashima Space Center
Spacecraft Mass	Approx. 4 tons
Generated Power	Approx. 7 kW (at End of Life)
Design Life	3 -5 years
Orbit	Sun-Synchronous Sub-Recurrent
	Repeat Cycle: 46 days Sub Cycle: 2 days
	Altitude: 691.65 km (at Equator)
	Inclination: 98.16 deg.
Attitude Determination Accuracy	2.0 x 10^{-4}degree (with GCP)
Position Determination Accuracy	1m (off-line)
Data Rate	240Mbps (via Data Relay Technology Satellite) 120Mbps (Direct Transmission)
Onboard Data Recorder	Solid-state data recorder (90Gbytes)

5.2.1.1 PRISM

The Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) is a panchromatic radiometer with 2.5m spatial resolution at nadir (Figure 5.3). Its extracted data will provide a highly accurate digital surface model (DSM). PRISM has three independent optical systems for viewing nadir, forward and backward producing a stereoscopic image along the satellite's track. Each telescope consists of three mirrors and several CCD detectors for push-broom scanning. The nadir-viewing telescope covers a width of 70km; forward and backward telescopes cover 35km each. The telescopes are installed on the sides of the optical bench with precise temperature control. Forward and backward telescopes are inclined +24 and -24 degrees from nadir to realize a base-to-height ratio of 1.0. PRISM's wide field of view (FOV) provides three fully overlapped stereo (triplet) images of a 35km width without mechanical scanning or yaw steering of the satellite (Table 5.2 and 5.3). Without this wide FOV, forward, nadir, and backward images would not overlap each other due to the Earth's rotation.

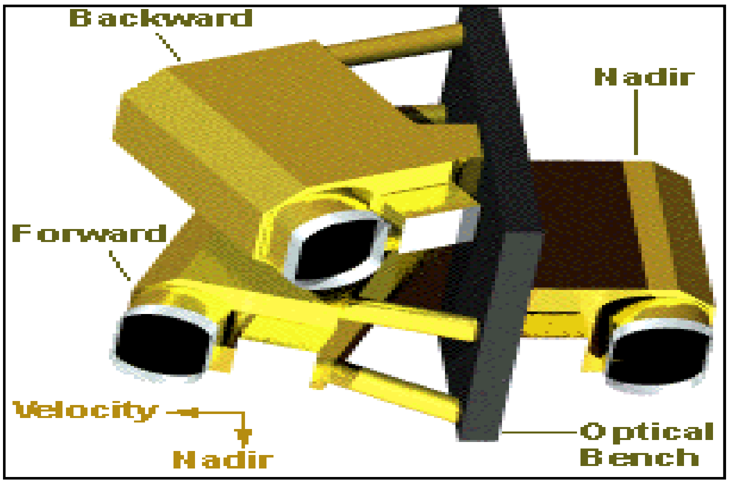

Figure 5. 3: PRISM.

Table 5.2: Characteristics of PRISM.

PRISM Characteristics	
Number of Bands	1 (Panchromatic)
Wavelength	0.52 to 0.77 micrometers
Number of Optics	3 (Nadir; Forward; Backward)
Base-to-Height ratio	1.0 (between Forward and Backward view)
Spatial Resolution	2.5m (at Nadir)
Swath Width	70km (Nadir only) / 35km (Triplet mode)
S/N	>70
MTF	>0.2
Number of Detectors	28000 / band (Swath Width 70km) 14000 / band (Swath Width 35km)
Pointing Angle	-1.5 to +1.5 degrees (Triplet Mode, Cross-track direction)
Bit Length	8 bits

Table 5.3: Observation modes of PRISM.

Observation Modes	
Mode 1	Triplet observation mode using Forward, Nadir, and Backward views (Swath width is 35km)
Mode 2	Nadir (70km) + Backward (35km)
Mode 3	Nadir (70km)
Mode 4	Nadir (35km) + Forward (35km)
Mode 5	Nadir (35km) + Backward (35km)
Mode 6	Forward (35km) + Backward (35km)
Mode 7	Nadir (35km)
Mode 8	Forward (35km)
Mode 9	Backward (35km)

5.2.1.2 AVNIR-2

The Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) is a visible and near infrared radiometer for observing land and coastal zones. It provides better spatial landcoverage maps and land-use classification maps for monitoring regional environments. AVNIR-2 is a successor to AVNIR that was on board the Advanced Earth Observing Satellite (ADEOS), which was launched in August 1996. Its instantaneous field-of-view (IFOV) is the main improvement over AVNIR. AVNIR-2 also provides 10m spatial resolution images, an improvement over the 16m resolution of AVNIR in the multi-spectral region. Improved CCD detectors (AVNIR has 5,000 pixels per CCD; AVNIR-2 7,000 pixels per CCD) and electronics enable this higher resolution. A cross-track pointing function for prompt observation of disaster areas is another improvement. The pointing angle of AVNIR-2 is +44 and -44 degree (Table 5. 4).

Table 5.4: Characteristics of AVNIR-2.

AVNIR-2 Characteristics	
Number of Bands	4
Wavelength	Band 1 : 0.42 to 0.50 micrometers Band 2 : 0.52 to 0.60 micrometers Band 3 : 0.61 to 0.69 micrometers Band 4 : 0.76 to 0.89 micrometers
Spatial Resolution	10m (at Nadir)
Swath Width	70km (at Nadir)
S/N	>200
MTF	Band 1 through 3 : >0.25 Band 4 : >0.20
Number of Detectors	7000/band
Pointing Angle	- 44 to + 44 degree
Bit Length	8 bits

5.2.1.3 PALSAR

The Phased Array type L-band Synthetic Aperture Radar (PALSAR) is an active microwave sensor using L-band frequency to achieve cloud-free and day-and-night land observation. It provides higher performance than the JERS-1's synthetic aperture radar (SAR). Fine resolution in a conventional mode, but PALSAR will have another advantageous observation mode. ScanSAR, which will enable us to acquire a 250 to 350km width of SAR images (depending on the number of scans) at the expense of spatial resolution (Table 5. 5). This swath is three to five times wider than conventional SAR images. The development of the PALSAR is a joint project between JAXA and the Japan Resources Observation System Organization (JAROS).

Table 5. 5: Characteristics of PALSAR.

PALSAR Characteristic				
Mode	**Fine**		**ScanSAR**	**Polarimetric (Experimental mode)*1**
Center Frequency	1270 MHz(L-band)			
Chirp Bandwidth	28MHz	14MHz	14MHz,28MHz	14MHz
Polarization	HH or VV	HH+HV or VV+VH	HH or VV	HH+HV+VH+VV
Incident angle	8 to 60deg.	8 to 60deg.	18 to 43deg.	8 to 30deg.
Range Resolution	7 to 44m	14 to 88m	100m (multi look)	24 to 89m
Observation Swath	40 to 70km	40 to 70km	250 to 350km	20 to 65km
Bit Length	5 bits	5 bits	5 bits	3 or 5bits
Data rate	240Mbps	240Mbps	120Mbps,240Mbps	240Mbps
NE sigma zero *2	< -23dB (Swath Width 70km) < -25dB (Swath Width 60km)		< -25dB	< -29dB
S/A *2,*3	> 16dB (Swath Width 70km) > 21dB (Swath Width 60km)		> 21dB	> 19dB
Radiometric accuracy	scene: 1dB / orbit: 1.5 dB			

5.3 Methods Used

5.3.1 Digital Terrain Model (DTM)

A Digital Elevation Model (DEM) is a digital representation of ground surface topography or terrain. It is also widely known as a digital terrain model (DTM). A DEM can be represented as a raster (a grid of squares) or as a triangular irregular network. DEMs are commonly built using remote sensing techniques, however, they may also be built from land surveying. DEMs are used often in geographic information systems, and are the most common basis for digitally-produced relief maps. By using benefits of DTM, we are able to obtain slope maps, aspect maps and various profiles (longitudinal and transverse sections of valleys, etc).

Digital elevation models may be prepared in a number of ways, but they are frequently obtained by remote sensing rather than direct survey. One powerful technique for generating digital elevation models is interferometric synthetic aperture radar; two passes of a radar satellite (such as RADARSAT-1) suffice to generate a digital elevation map tens of kilometers on a side with a resolution of around ten meters. One also obtains an image of the surface cover.

Another powerful technique for generating a Digital Elevation Model is using the Digital image correlation method. It implies two optical images acquired with different angles taken from the same pass of an airplane or an Earth Observation satellite (such as the HRS intrument of SPOT5).

Older methods of generating DEMs often involve interpolating digital contour maps that may have been produced by direct survey of the land surface; this method is still used in mountain areas, where interferometry is not always satisfactory. Note that the contour data or any other sampled elevation datasets (by GPS or ground survey) are not DEMs, but may be considered Digital terrain models. A DEM implies that elevation is available continuously at each location in the study area.

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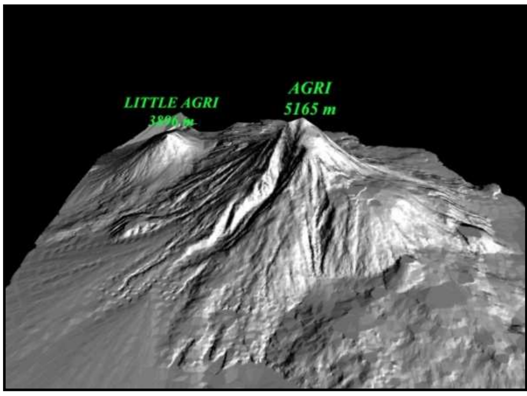
5.3.2 DTM Generation From Topographical Maps

DTMs can be obtained by using different methods such as stereoscope satellite images and land readings. Having been used as the basis of this study, the 1/25000 scaled topographic maps were digitised by using 10 m contour line intervals. First the irregular Triangle Network (TIN) was generated from the contour line curves and altitude points using the 3D Analyst module. All points in this data structure are generally interconnected via Delaunal triangulation, which combines the centres of adjacent thiessen polygons (Kumler, 1994). The TIN model is then converted into raster format and DTM is generated accordingly. The grid size of this conversion was 10 m. Selection of this value was affected by the use of contour lines at either 10 m or 5 m intervals. Having been created from contour lines, the DTMs with small intervals feature higher altimetry accuracy and constitute useful data resources (Wilson and Gallant, 2000). The 3D model was created by using the generated DTM (Figure 5.5). The DTM was also used to create the Hillshade 3D model (Figure 5.4) (Akar, 2008).



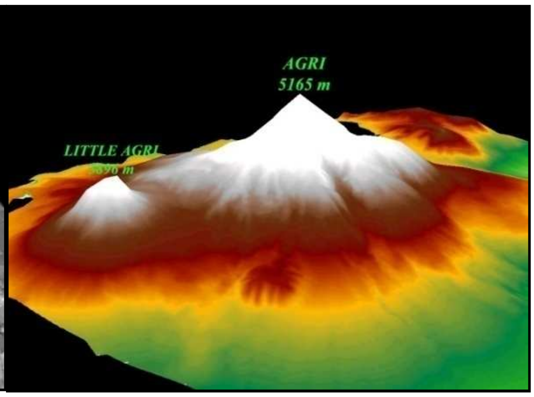


Figure 5.4: Hillshade model. **Figure 5.5:** DTM.

5.3.3 DTM Generation From Stereo Images

Actual very high resolution (VHR) satellite image data with resolution of about one meter offer the possibility to see many details in urban areas. Objects like houses, trees and cars can be interpreted easily with visual methods, while the automatic interpretation of this kind of space borne data is still a very busy field of research. Especially, an automatic DTM generation from along track stereo pairs of VHR optical data from space, like IKONOS or Quick Bird images, offer new challenges for developing techniques for the automatic interpretation of homologous image structures and further for object extraction (Figure 5.6). So, at present a primary target in city modelling is the quest for algorithms creating fully automatically good and reliable digital elevation models from relatively easy to acquire high resolution stereo satellite imagery [1, 2] [12].

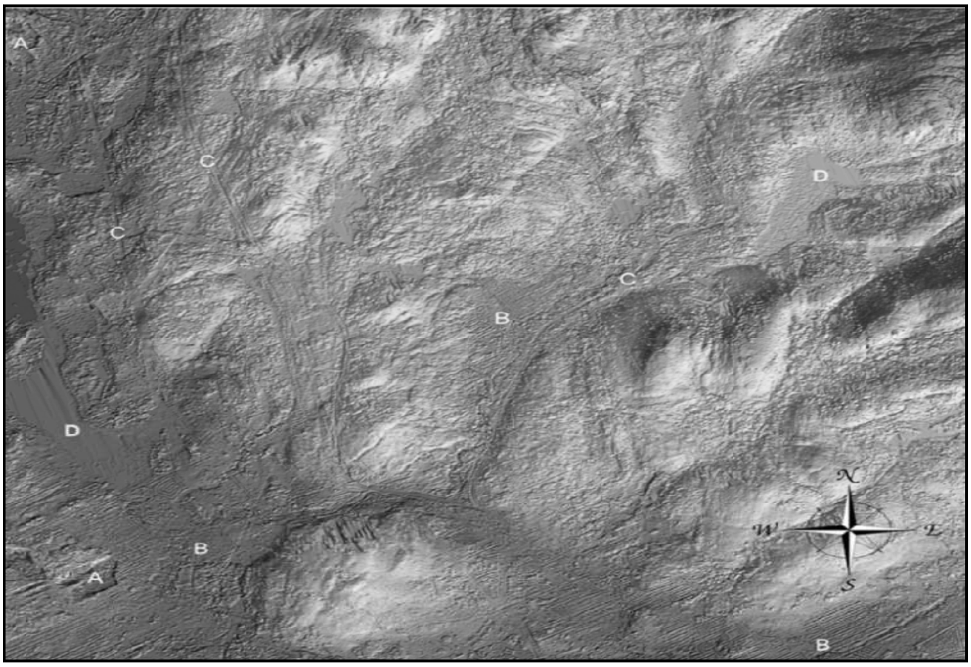


Figure 5.6: DTM extracted from IKONOS-II stereo-pair.

Among the sources of satellite imagery that are available in the market, SPOT has always been popular with the photogrammetric community especially for use in 3D topographic mapping. A detailed review of published results on the geometric accuracy and digital elevation model generation/validation from earlier SPOT missions was carried out by Al-Rousan (1998) (Büyüksalih and Koçak, 2005). The SPOT 5 satellite includes the imaging instruments known as High Resolution Geometric (HRG), High Resolution Stereoscopic (HRS) and Vegetation. A pair of HRG pushbroom scanners operating side by side provide panchromatic images with 5 m ground pixel size in the standard mode and 2.5 m in ‘‘supermode’’ while maintaining the 60 km swath width of the previous SPOT satellites. However, a major innovation for SPOT 5 is the HRS imager with its along-track stereo capability, designed specifically to produce DEMs over a 120 km swath (Büyüksalih and Koçak, 2005).

5.3.4 DTM Generation From SRTM

The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. The Shuttle Radar Topography Mission instrument consisted of three sections

(Figure 5. 7). The main antenna was located in the payload bay of Space Shuttle Endeavour, the mast was connected to the main antenna truss, and an outboard antenna was connected to the end of the mast.

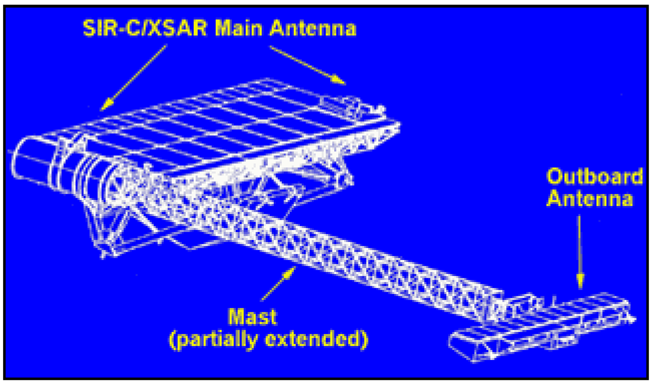


Figure 5. 7: SRTM Instrument.

In order to gather topographic (elevation) data of Earth's surface, SRTM used the technique of interferometry. In interferometry, two images are taken from different vantage points of the same area. The slight difference in the two images allows scientists to determine the height of the surface.

The main antenna actually consisted of two antennas and the avionics that computed the position of the antennas. Each antenna was made up of special panels that could transmit and receive radar signals. One antenna was called the C-band antenna and could transmit and receive radar wavelenths that are 5.6 centimeters long. During the mission the C-band radar, with a swath width (width of the radar beam on Earth's surface) of 225 kilometers, scanned about 80% of the land surface of the Earth.

The other antenna was the X-band antenna. This antenna could transmit and receive radar wavelenths that are 3 centimeters long. The X-band radar, with a swath width of 50 kilometers, will produce topographic maps at a somewhat higher resolution than the C-band data, but will not have near-global coverage (Figure 5.8) [13].

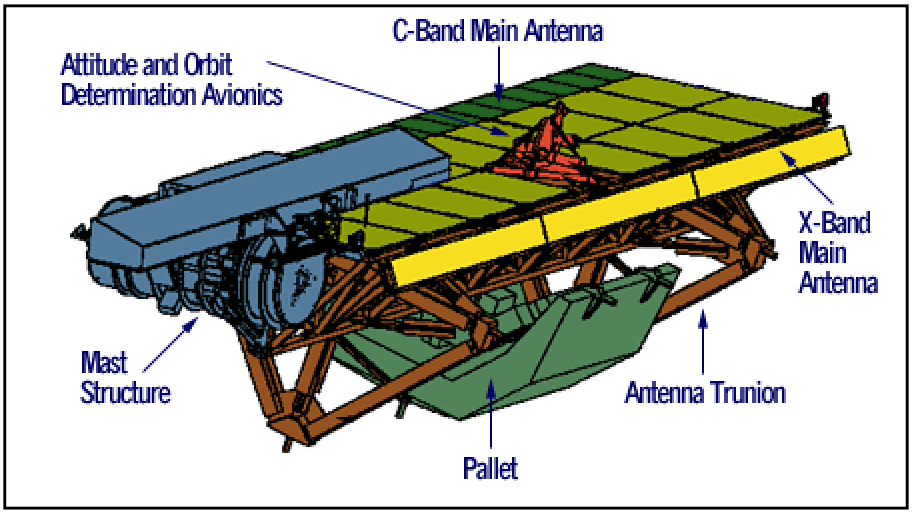


Figure 5.8: Main antenna of SRTM.

Digital elevation models (DEMs) are a basic component of any geoinformation system (GIS). The terrain cannot only be described by the horizontal components; the height belongs to complete information. In addition height models are required for the generation of orthoimages – one of the most often used photogrammetric product. DEMs can be generated by laser scanning, photogrammetric methods or interferometric synthetic aperture radar (InSAR). In any case it is time consuming and expensive. The worldwide lack of qualified and accessible DEMs has been improved with the Shuttle Radar Topography Mission (SRTM) in February 2000. Based on InSAR height models have been generated covering the world from 56° southern up to 60.25° northern latitude. The DEMs based on the US C-band are available free of charge on the internet with a spacing of 3 arcsec, corresponding to approximately 92m at the equator. Only for the USA data with a spacing of 1 arcsec (~ 30m) are also in the WEB. The DEMs based on the German / Italian X-band can be ordered from the DLR, Germany with a spacing of 1 arcsec. But without scanSAR-mode the X-band DEM has large gaps between the swaths of 45km width.

The nearly worldwide and free of charge available SRTM C-band height models are an important component of the knowledge about our spatial environment (Figure 5. 9). The homogenous accuracy is sufficient for several applications and for wide areas of the world it is more detailed information about the surface than known before [14].

Figure 5.9: DEM generation from SRTM data.

5.4 Methodology

5.4.1 DTM Generation From Topographical Maps

1/25000 scaled topographic maps were digitised by using 10 m contour line intervals (Figure 5.10). First the Triangle irregular Network (TIN) ((Figure 5.11) was generated from the contour line curves and altitude points using the 3D Analyst module. All points in this data structure are generally interconnected via Delaunal triangulation. The TIN model is then converted into raster format and DTM is generated accordingly (Figure 5. 12). The grid size of this conversion was 10 m. Also, DTM of study area and overlapping of IKONOS image on this DTM are shown below (Figure 5. 13).

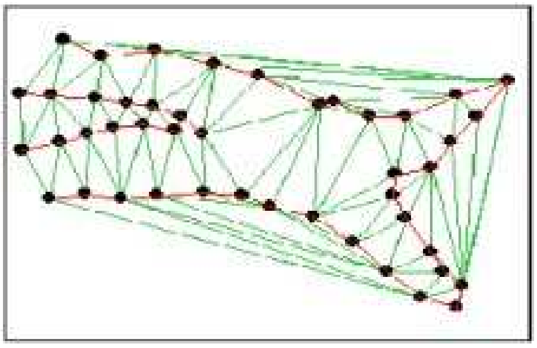


Figure 5.10: Contour line. **Figure 5.11:** Triangle Irregular Network (TIN).

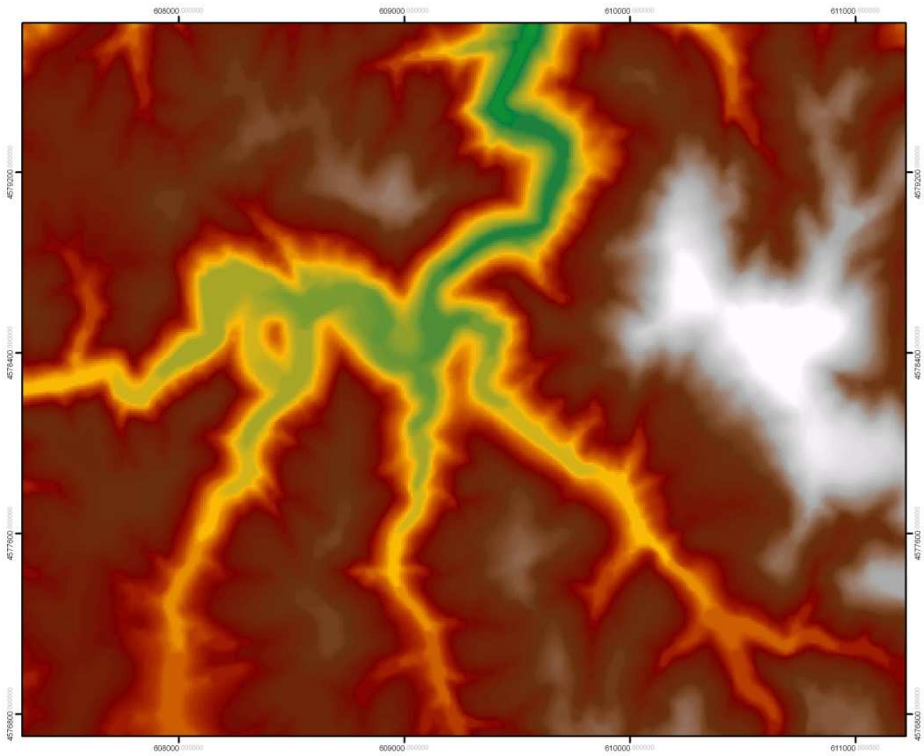


Figure 5.12 : DTM Generation From Topographical Maps.

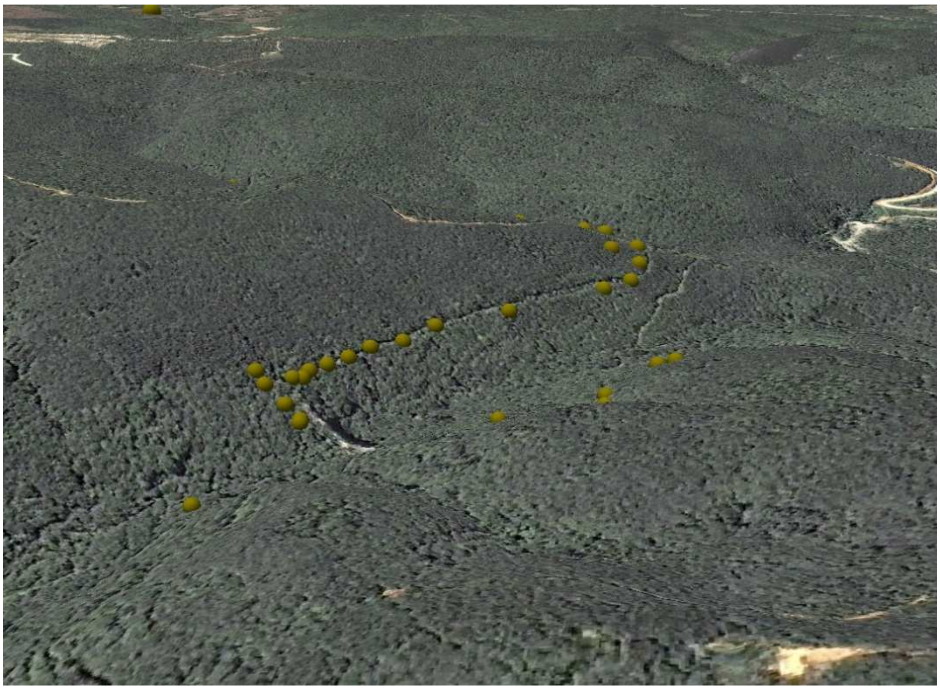


Figure 5.13 : Overlapping of IKONS Image on DTM Generated Topographical Maps

5.4.2 DTM Generation From SRTM

The DEMs based on the US C-band are available free of charge on the internet with a spacing of 3 arcsec, corresponding to approximately 92 m at the equator.

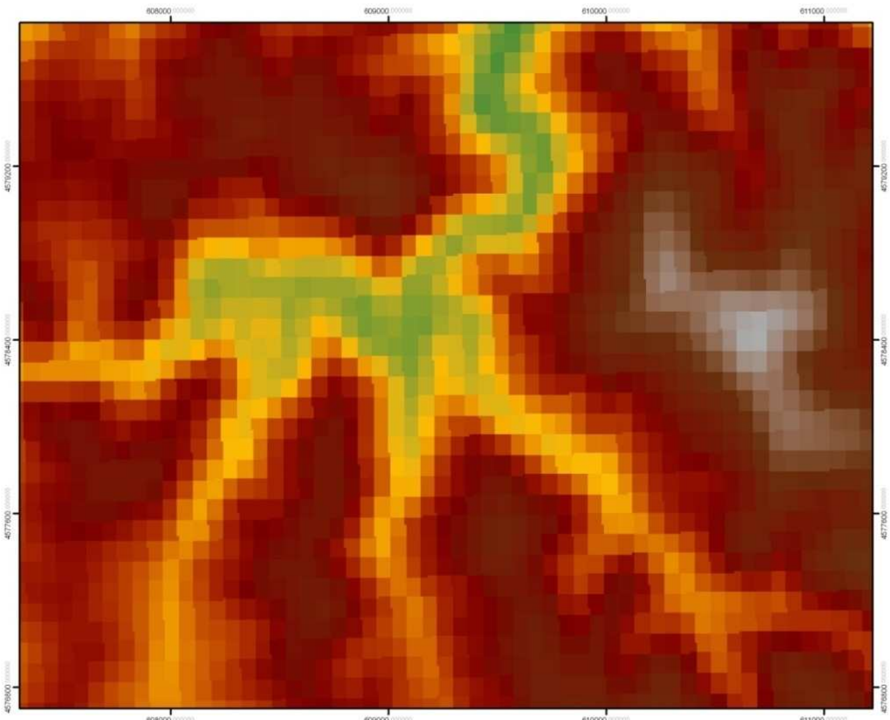


Figure 5.14 : DTM Generation From SRTM.

Also, DTM of study area and overlapping of IKONOS image on this DTM are shown below (Figure 5.14 and 5.15).

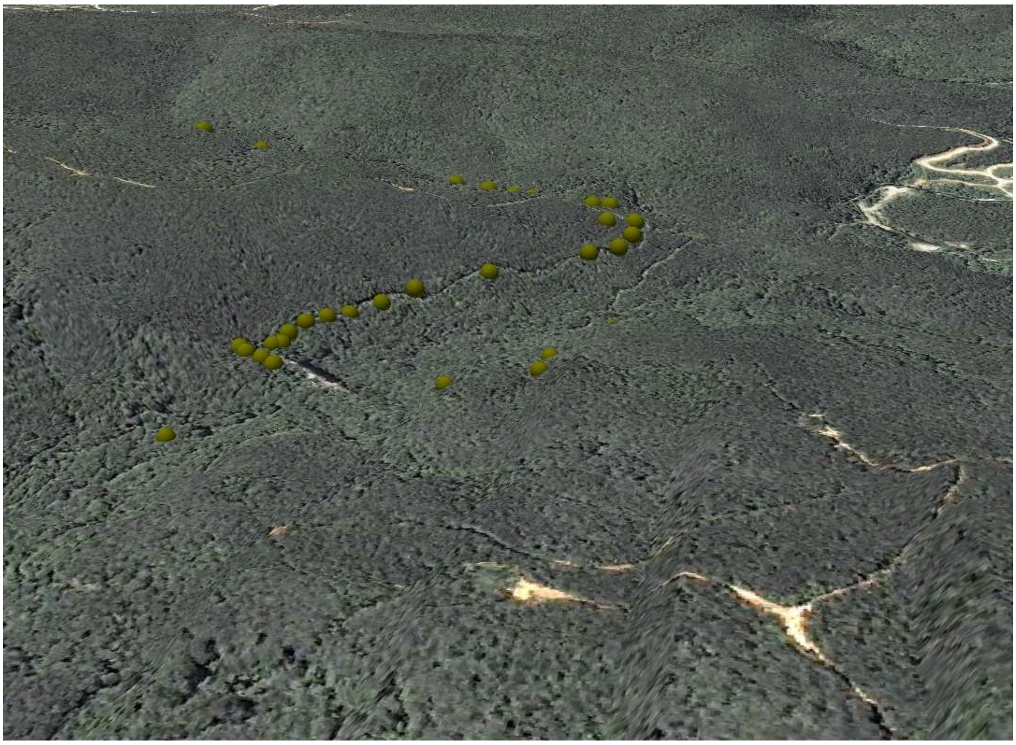


Figure 5.15 : Overlapping of IKONOS Image on DTM Generated from SRTM.

5.4.3 DTM Generation From Stereo Images

To generate DTM, ALOS Prism stereo images (triplet mode) are used (Figure 5.16) . This data has georeferenced, nearest neighbour, UTM projection. Also it has level 1B2. At this study, backward and nadir images were selected to generate DTM. Their swath area consist of 35 km².

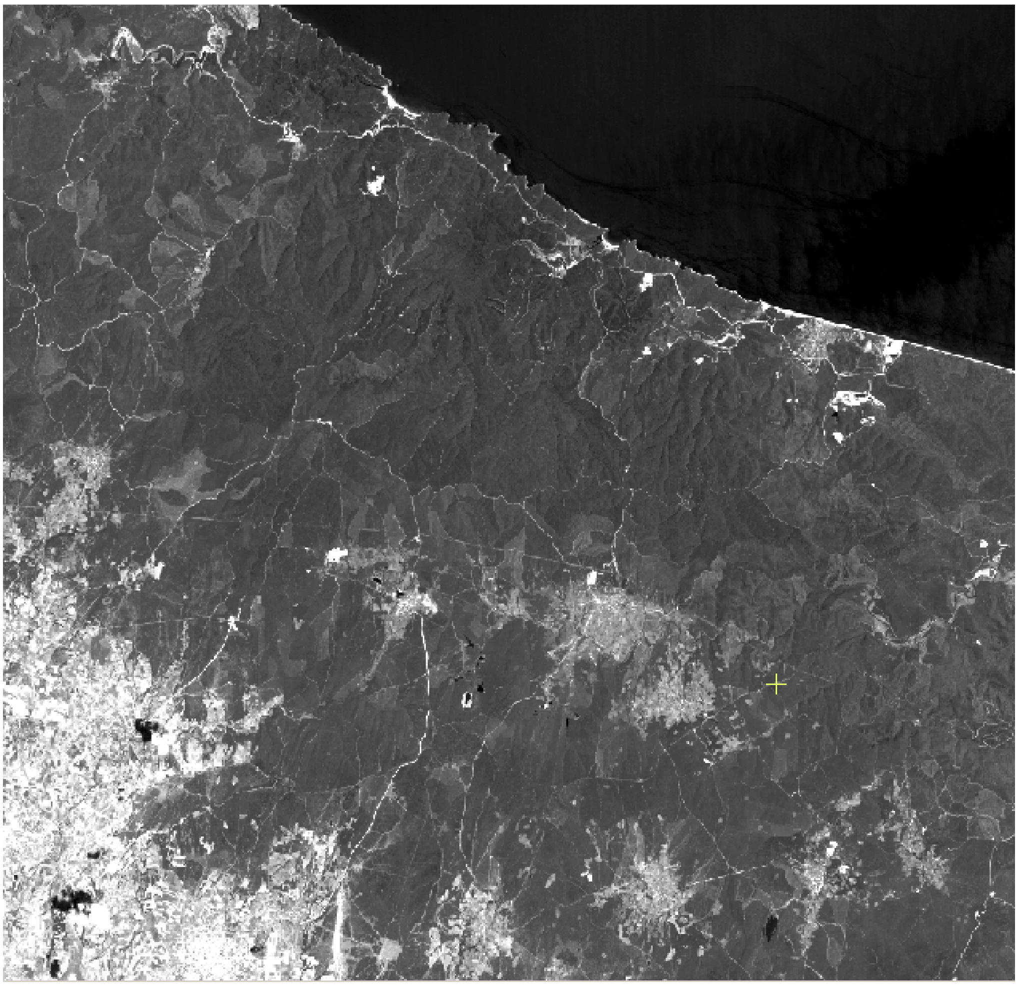


Figure 5.16 : ALOS Prism Image.

Firstly, a new project was created with using OrthoEngine module (Figure 5.17). Then Project information was selected. The next step was to define the projection (Figure 5.18). It was entered in the appropriate projection information for the PRISM dataset. It was recommended that we use “Set GCP Projection based on Output Projection” option for the GCP projection.

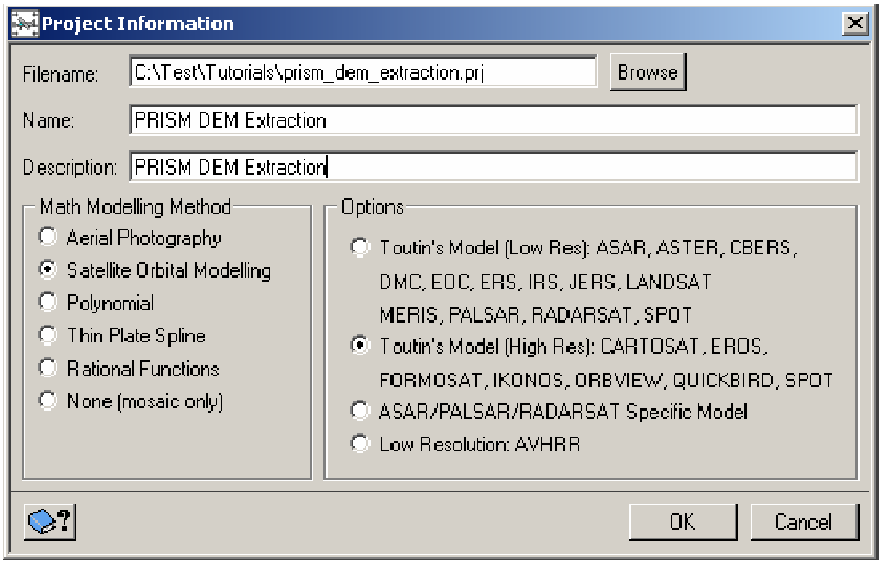


Figure 5.17 : Project Information.

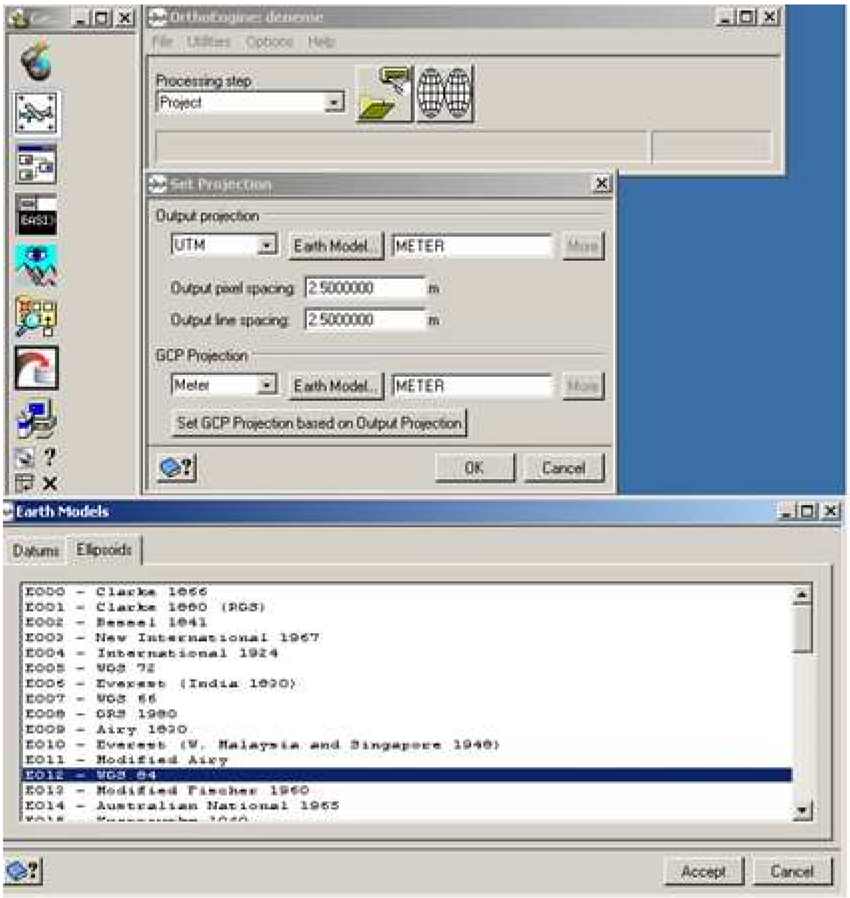


Figure 5.18 : Projection Information.

Secondly, it was aimed import PRISM imagery into project. The dataset shows stereo imagery from a single PRISM CCD, there are two types of files. One type is prefixed with the term "IMG" and the other type is prefixed with the term "VOL". The "VOL" files simply maintain information about the dataset, such as the images included in the dataset, their associated channel, and filename. The "IMG" files are the actual images in each dataset. Note that both file types end with either "_N" or "_B". N indicates nadir view, and B indicates backward view. Therefore, "VOL" files ending in "_B" maintain information about the backward view dataset, and "VOL" files ending in "_N" maintain information about the nadir view dataset.

To begin importing the PRISM imagery into project:

- Orthoengine select "Data Input" from the processing step, and Click "Read CD- ROM data"(Figure 5.19).
- In the Read CD-ROM data window, select "PRISM (LGSOWG)".
- Select the CD header filename (the VOLUME file).
- Select the channel to import. For example, if the imagery provided is prefixed by "IMG-05" then this would indicate that the channel is 5.
- Once the channel is selected, provide an appropriate PCIDSK filename and click READ.
- Repeat this procedure for all images in both the nadir and backward views.

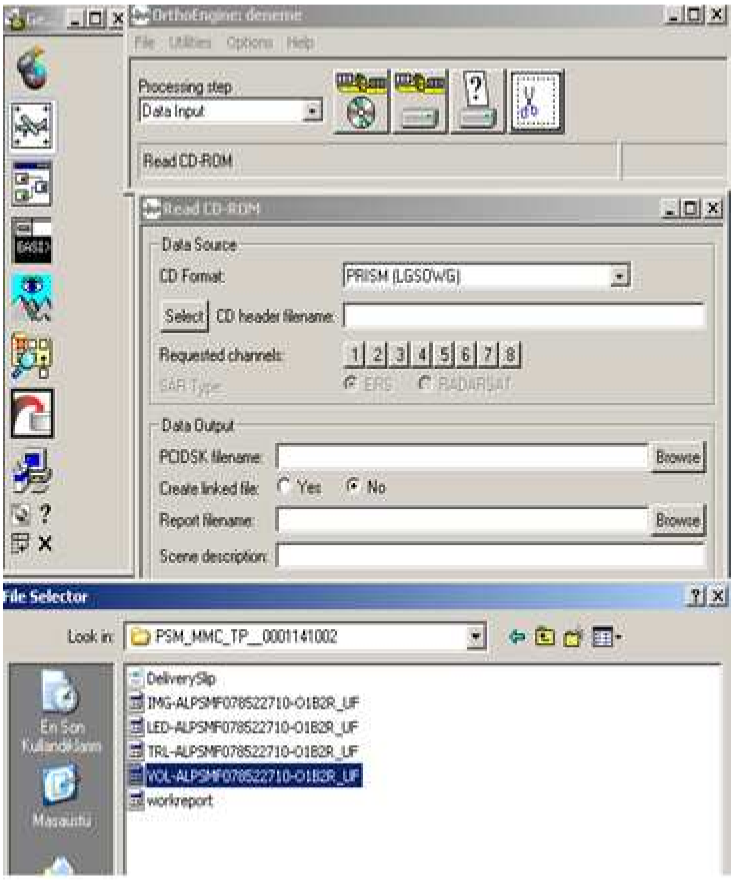


Figure 5.19 : Data Input.

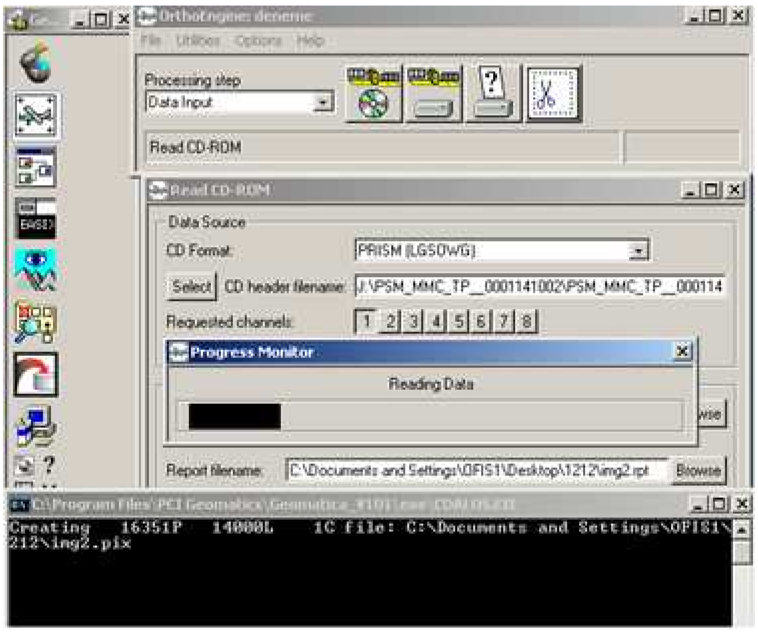


Figure 5.20 : Format Changing.

Thirdly, once the imagery has been imported into PIX format, opened a stereo pair (Figure 5.20) . In the processing step drop down in Orthoengine, selected “GCP/TP

Collection" and clicked the "Open a new or existing image" button. Once both images were opened, one of them was reference, and the other was working position (Figure 5.21 and 5.22).

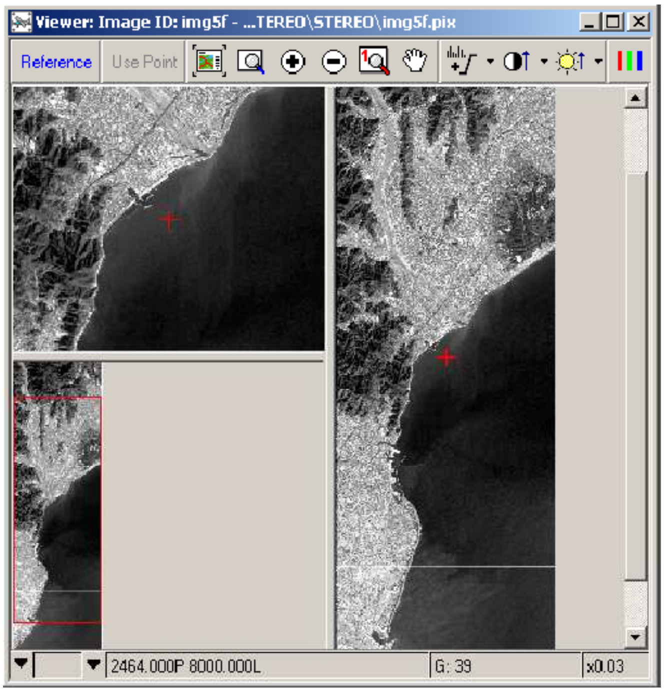


Figure 5.21 : Reference Image.

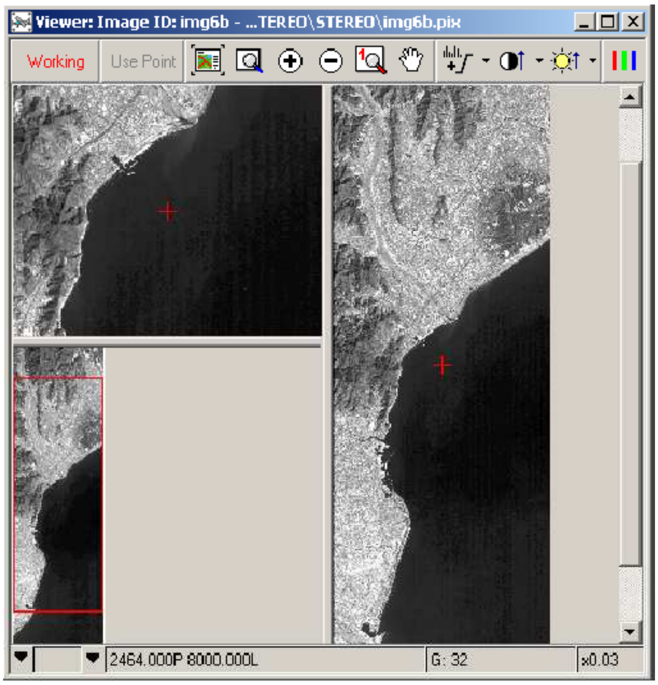


Figure 5.22 : Working Image.

The next step was collection of stereo GCPs. Now that the images have been opened, it’s time to start collecting Stereo GCPs. Stereo GCPs are GCPs that are present in both images. These are advantageous for several reasons. Firstly, Stereo GCPs are useful because they can be used to derive elevation information from a stereo dataset. This is the result of the parallax difference which occurs between the stereo pair. Secondly, Stereo GCPs are heavily weighted in the adjustment model. It is important when collecting Stereo GCPs that the user take the utmost care to ensure that accurate and precise Stereo GCPs are chosen.

• Selected the first image we would like to collect a GCP in by setting it to the working image. The working image chosen for this example is the nadir view image.

• In the working image viewer, located a clearly identifiable point we would like to use as a GCP and click “Use Point”.

• To ensure better results, make sure that the GCP we choose is a well defined location in our image (such as an intersection of two roads). Also ensure that the GCP is identifiable in both images in the stereo pair, and the control source image.

• Notice that after we clicked “Use Point” the GCP Collection Window updates with the pixel and line location of the GCP (Figure 5.23).

• Then located the same location (in this case, G0001) in the geocoded image. Be sure to get as close as possible to the same location as that in our working image.

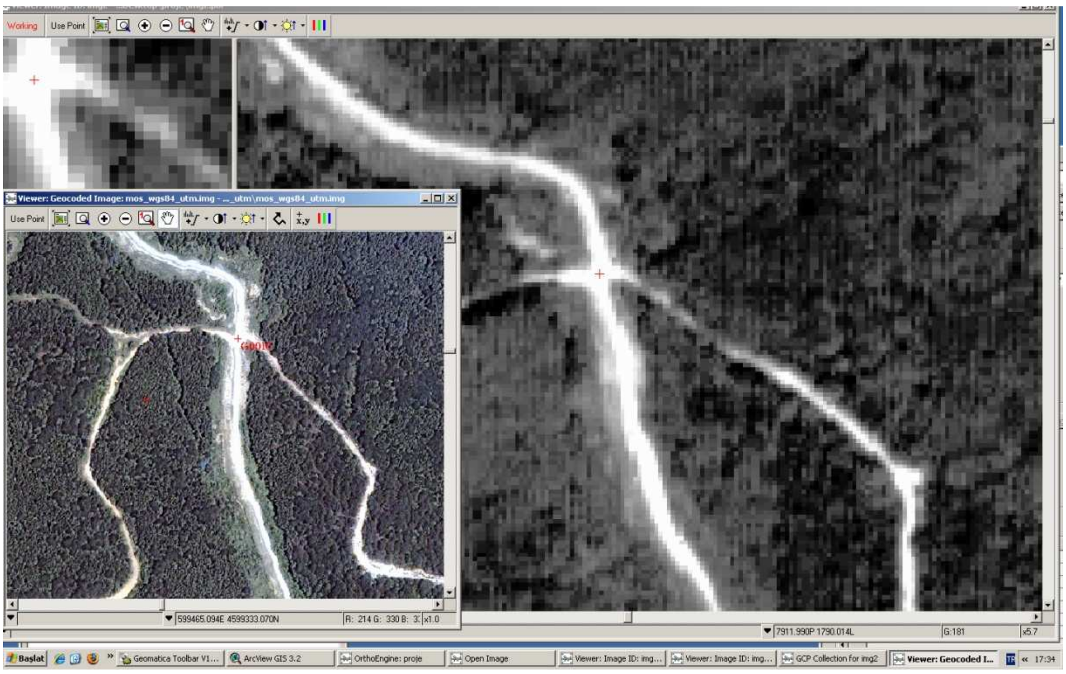


Figure 5.23 : Selection of GCP.

• Once we have found the same point, clicked “Use Point” in the control source image window. Noticed that the Eastings and Northings information was added to the GCP collection Window.
• Entered the elevation of your GCP (if it is known), or used “Extract Elevation” to extracted the elevation value for this GCP from your DEM.
• In the GCP Collection Window, Clicked Accept. Noticed that the new GCP (in this case, G0001) is now added to the Accepted Points section
• Now the same GCP must be collected in the other image in the stereo pair. Changed the Viewer Window Status of the second image in the stereo pair from Reference to Working.
• In the GCP collection window, changed the Point ID to the same Point ID just collected in the other image. This allows Orthoengine to reference the same Easting, Northings and Elevation information from the previous image. The Easting and Northing information was updated as shown there.
• Clicked “Use Point” for this Working Image and noticed that the pixel and line coordinates of the GCP were added to the GCP collection window.
• Clicked “Accept” in the GCP Collection Window to add the stereo GCP.
• Then repeated the same process to collect other stereo GCPs.

At this study, 82 points were selected GCPs but only 32 points of them were used. The other points were eliminated because of some reasons. GCPs were selected from IKONOS images, DTM generating from1/25000 scaled topographical maps and GPS measurements of the fieldwork.

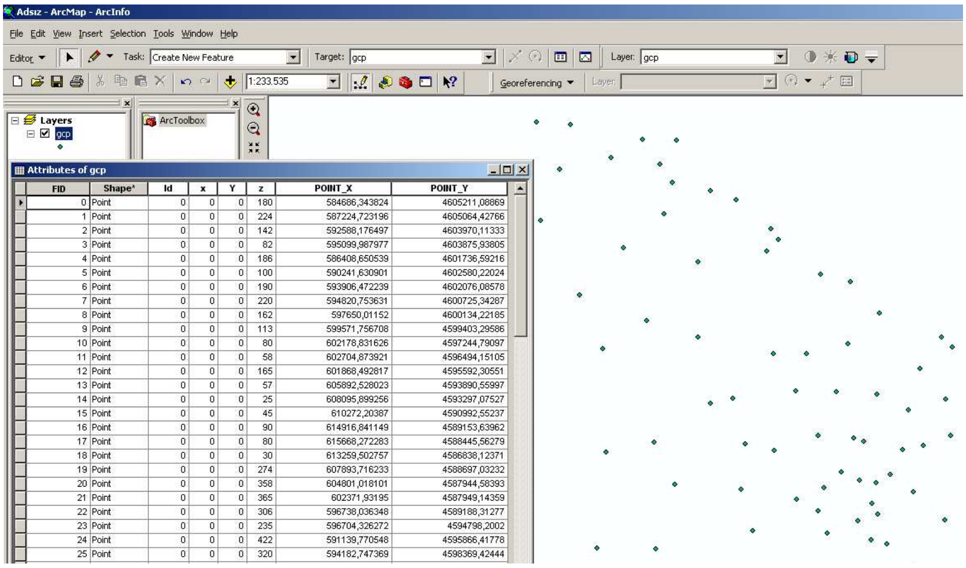


Figure 5.24 : All Grand Control Points.

After that, all GCPs have been collected, switched to "Model Calculations" in the processing step of Orthoengine and clicked the " Compute Model" buton (Figure 5.24).

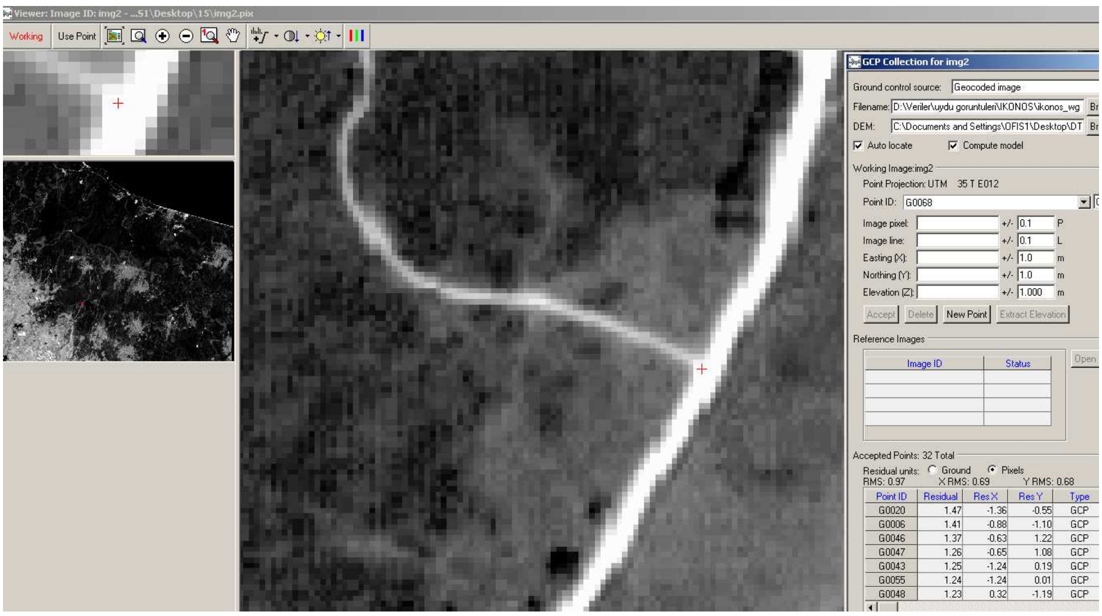


Figure 5.25 : RMS Value.

After model calculation, RMS value was calculated as 0.6 (Figure 5.25).

Finally, to extract DTM from stereo:

• In Orthoengine, switched to the “DEM From Stereo” option in the processing step. Then clicked the “Create Epipolar Image” button. The generate epipolar images window appears (Figure 5.26).

• In the generate epipolar images window, selected a left image and right image. Then clicked add epipolars to table. The epipolar pairs were then added to the epipolar pairs table. For this example, it was used a down sample factor of 2.

• Then clicked generate pairs to generate the epipolar images. (This may take some time depending on file size).

• Now that the epipolar pairs have been generated,
clicked the “Extract DEM automatically” button in Orthoengine

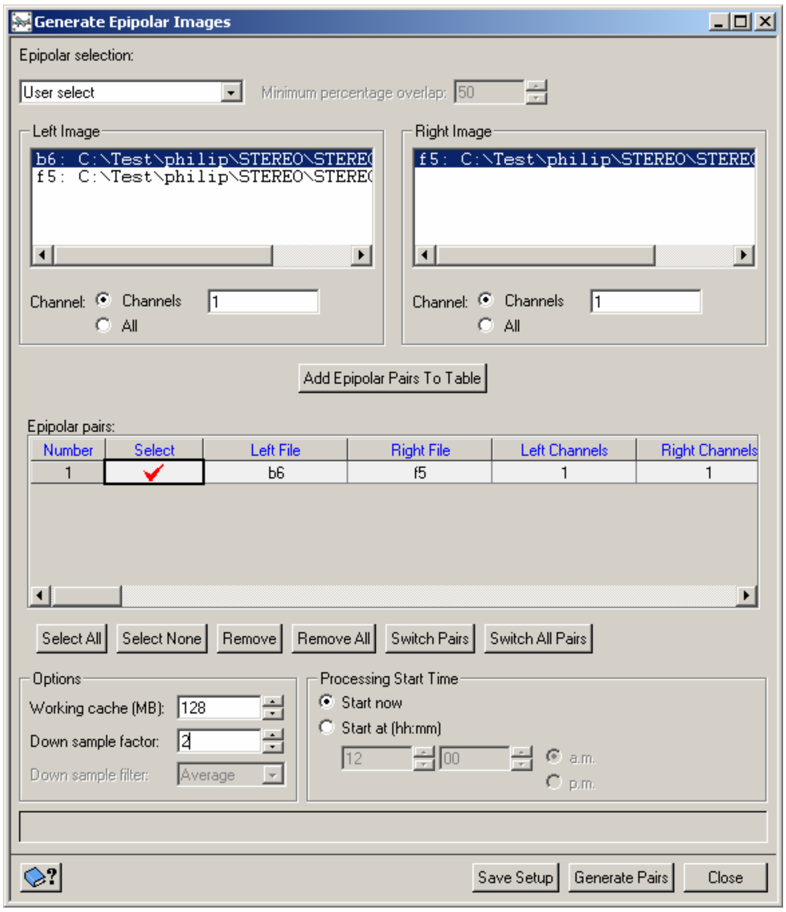


Figure 5.26 : Generating Epipolar Image.

• In the Automatic DEM extraction window, put a checkmark next to the stereo pair we were working with and set a pixel sampling interval of 1. Selected the option "Create Geocoded DEM" and choose an output filename for the DEM.

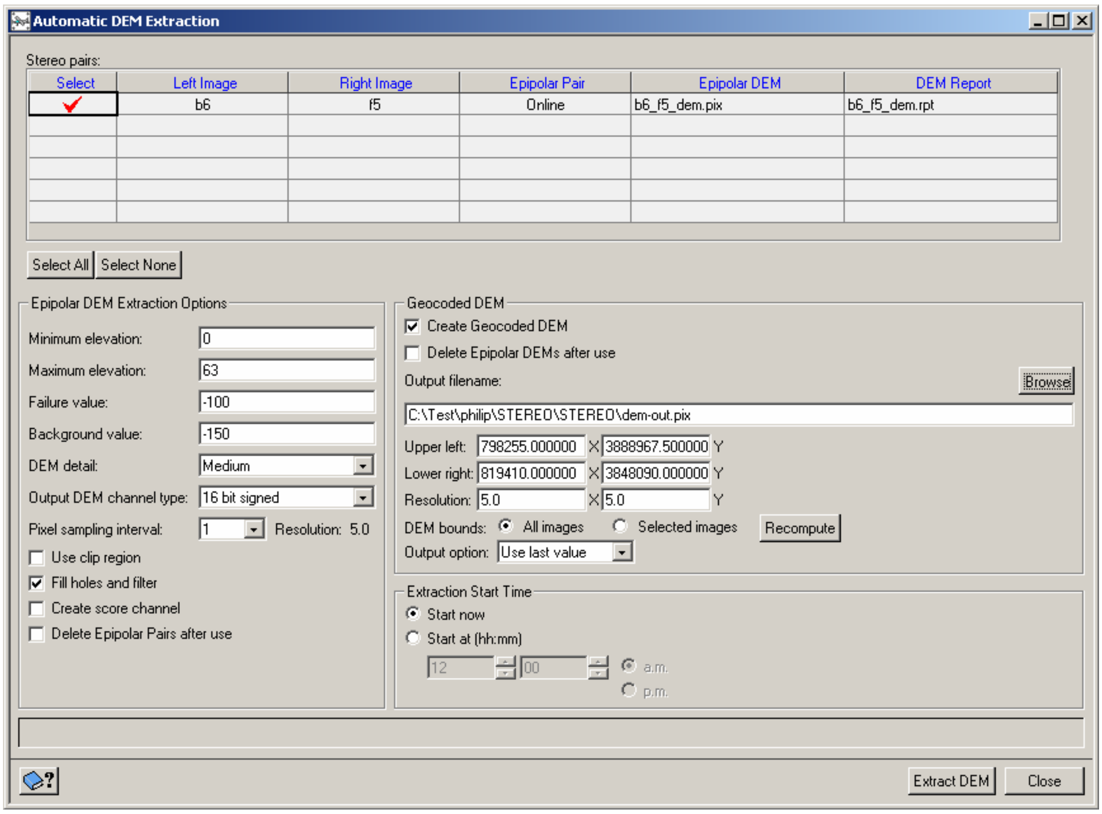


Figure 5.27 : Automatic DEM Extraction.

After clicked Extract DEM, the result was acquired successfully (Figure 5.27). Also, DTM of study area and overlapping of IKONOS image on this DTM are shown below.

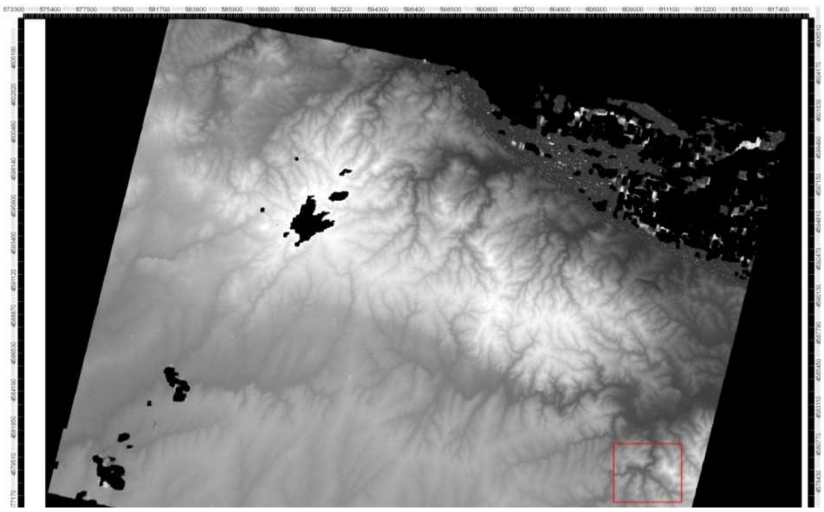


Figure 5.28 : DTM Generated From Prism Image.

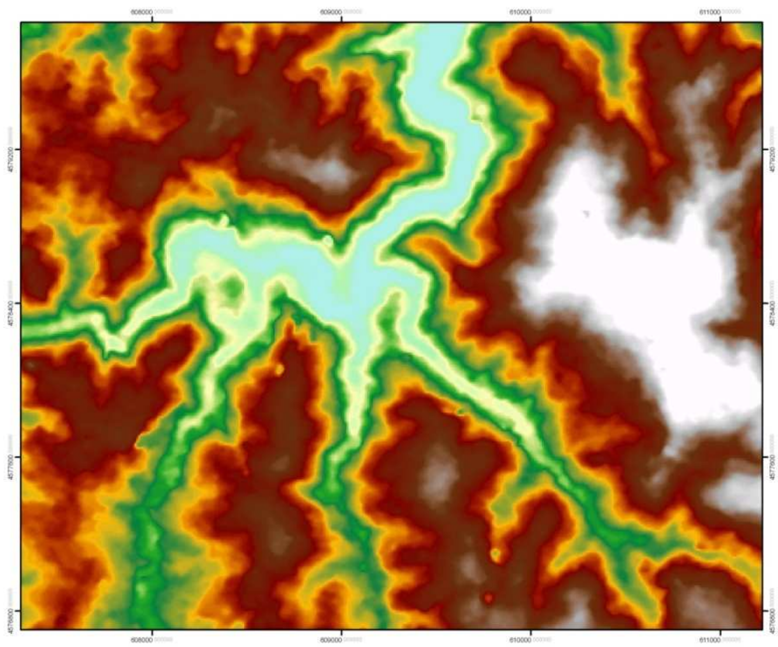


Figure 5.29 : Study Area of DTM Generated From Prism Image.

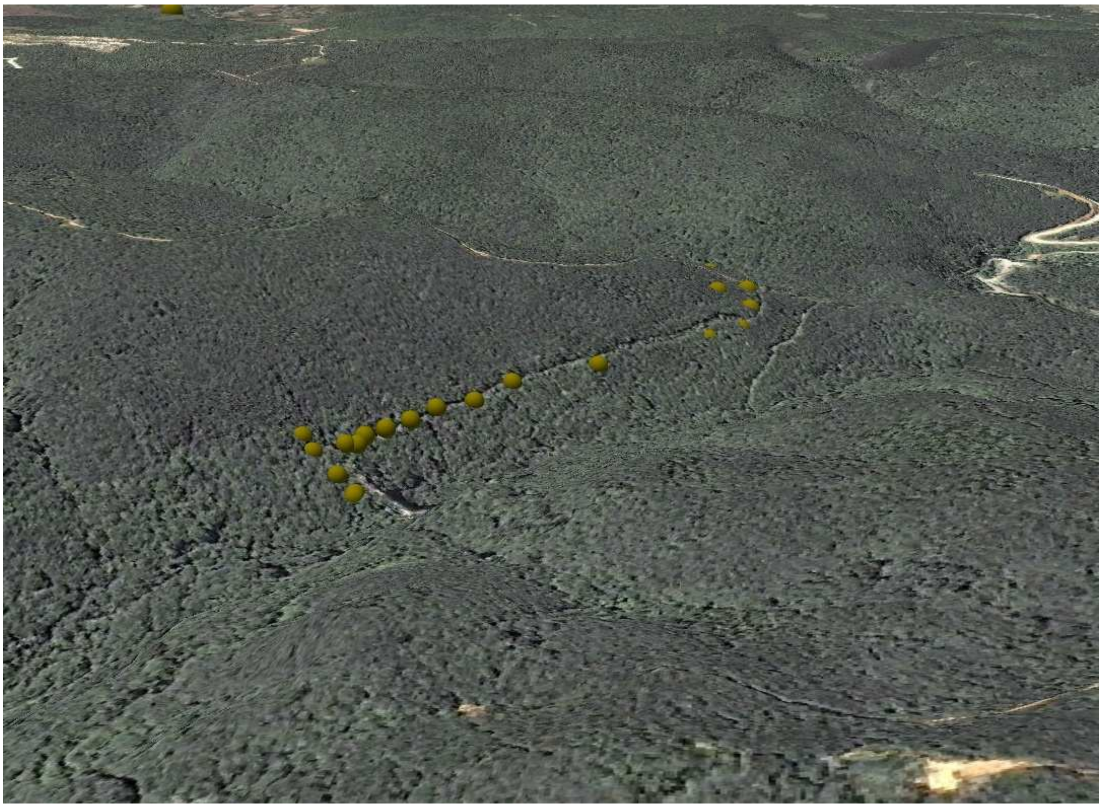


Figure 5.30 : Overlapping of IKONOS Image on DTM Generated From Prism Image

5.4.4 Generation And Using GIS

At this study, ArcGIS 9.2 was selected and used as a geographic information system software. Satellite data, GPS points and three DTM's which were generated from different resources were added as layers (Figure 5.31). Morever, overlapping of IKONOS image on DTM generated from SRTM, stereo images and topographical maps was composed. At the end of ongoing Tübitak project, all data (hydrological, archaeological, and others) will have been added to this system. So, some processes like inquiry and analysis will be available using GIS.

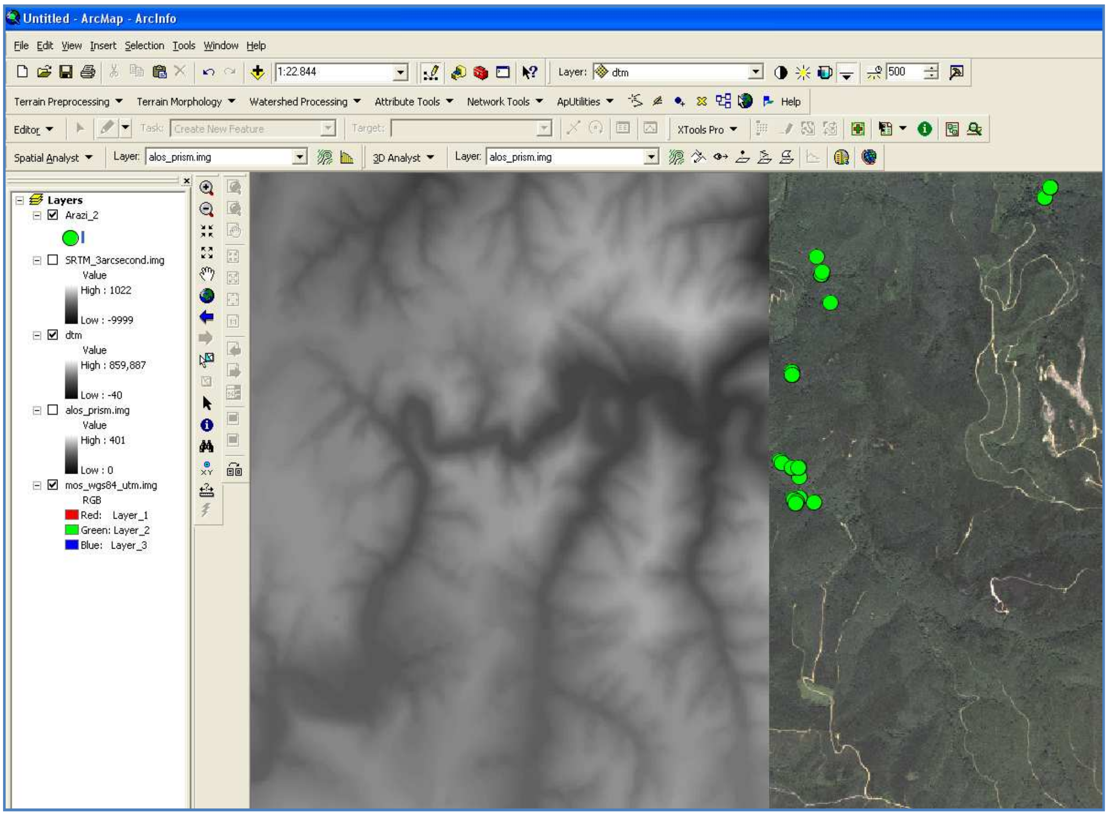


Figure 5.31 : Generation and using GIS.

6. RESULTS

Improvements at satellite technologies and information systems has caused the frequently usage of remote sensing and integration of geographic information system in archaeological applications. İstanbul has a remarkable strategical and geographical location that being influenced by many empires during history. Therefore, it has a rich cultural inheritance. At this study, Kurşunlugerme aqueduct in Çatalca District of İstanbul has been the important part of water supply system at the time of Roman, Byzantine and Otoman Empires, and its environment has been chosen. Three types of DTM were generated from different resources. When we compare two DTM (1/25000 topographical maps and ALOS Prism stereo images), they have nearly same accuracy values. The other DTM generating from SRTM has lower accuracy (6-7 meters) than the others. If it has been taken better accuracy GCPs in DTM generating from Prism stereo images, the result would be more precise and reliable. The three dimensional model, which can get by overlapping satellite images onto regional digital terrain models, can provide the terrain topography to demonstrate. Vital analyses and comments may make by adding GPS measurements at archaeological structures at study area. In conclusion, these archaeological structures should be preserved with using GIS and remote sensing technologies.

REFERENCES

Akar, İ., 2008, Application of GIS and Remote Sensing Generating in 3D Modeling and Determination of morphological Features with in "Ağrı Volcano" Ağrı, Turkey.

Allen, Kathleen M.S., Stanton W. Green and Ezra B.W. Zubrow. 1990. Interpreting Space: GIS and Archaeology. Taylor and Francis, London.

Büyüksalih, G., Koçak, G., Topan, H., Oruç, M., Marangoz, A., 2005, SPOT Revisited: Accuracy Assessment, DEM Generation and Validation from Stereo SPOT 5 HRG Images, *Photogrammetric Record*, 20(110), 1-18 (2005).

Campbell, J.B. (2002), *Introduction to Remote Sensing*, 3rd ed., The Guilford Press, New York, NY Clark et al., 1998 C.D. Clark, S.M. Garrod and M.P. Pearson, Landscape archaeology and remote sensing in southern Madagascar, International Journal of Remote Sensing **19** (1998) (8), pp. 1461–1477.

Chandra, A. M., Ghosh S. K., 2006, Remote Sensing and Geographical Information System, pp. 145 – 154.

Changlin, W., Ning, Y., Yueping, N., Lin, Y., 2004. Environmental Study and Information Extraction of Archaeological Features with Remote Sensing Imagery in Arid Area of Western China, *Proceedings of the International Conference on Remote Sensing Archaeology*, Beijing.

Emmolo, D., Franco, V., Lo Brutto, M., Orlando, P., Villa, B., 2004. Hyperspectral Techniques and GIS for Arechaeological Investigation, *Proceedings of the XXth ISPRS congress on Geo-imagery Bridging Continents*, Istanbul, Turkey.

Jensen, J. R. 2000, Remote Sensing of the Environment: An Earth Resource Perspective. Prentice Hall: New York.

Kumler, Mark P. (1994) “An Intensive Comparison of Triangulated Irregular Networks (TINs) and Digital Elevation Models (DEMs)”. Cartographica. Vol. 32, No. 2. Monography 45.

PCI Geomatics, 1998 PCI Geomatics, OrthoEngine reference manual, PCI Geomatics, Ontario (1998).

P.J. Gibson, 2000, Introductory Remote Sensing, Princicles and Concepts, Routledg.

Renfrew, C., Bahn, P., 2000, Archaeology: Theories, Methods, and Practice. Third edition. New York: Thames and Hudson.

Sever, T.L., 1995 Sever, Remote Sensing. In: P.E. McGovern, T.L. Sever, J.W. Myers, E.E. Myers, B. Bevan, N.F. Miller, S. Bottema, H. Hongo, R.H. Meadow, P.I. Kuniholm, S.G.E Bowman, M.N. Leese, R.E.M. Hedges, F.R. Matson, I.C. Freestone, S.J. Vaughan, J. Henderson, P.B. Vandiver, C.S. Tumosa, C.W. Beck, P. Smith, A.M. Child, A.M. Pollard, I. Thuesen and C. Sease, Editors, Science in Archaeology, *American Journal of Archaeology* **99** (1995) (1), pp. 83–84.

V. De Laet, E. Paulissen, M. Waelkens (2007). “Methods for the extraction of archaeological features from very high resolution Ikonos-2 remote sensing imagery, Hisar (southwest Turkey).” *Journal of Archaeological Science* 34(5): 830-841 (SCI: 1.316).

M. Waelkens, H. Vanhaverbeke, E. Paulissen, J. Poblome, J. Reyniers, W. Viane, J. Deckers, B. Decupere, W. Van Neer, H.A. Ekinci and M.O. Erbay, The 1996 and 1997 survey season at Sagalassos. In: M. Waelkens and L. Loots, Editors, Sagalassos V, Report on the Survey and Excavation Campaigns of 1996 and 1997, Acta Archaeologica Lovaniensia Monographiae 11A, Leuven University Press, Leuven (2000), pp. 17–216.

Wilson JP, Gallant JC (2000) Terrain analysis: principles and applications. John Wiley and Sons, Inc.: New York.

Wüst, T., Nebiker, S. und Landolt, R., 2004. Applying The 3D DIS DILAS to Archaeology and Cultural Heritage Projects – Requirements and First Results, XX ISPRS Congress. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences,* Vol. XXXV-B5, Istanbul, Turkey.

[1] http://en.wikipedia.org/wiki/Archaeology

[2] http:// www.arkeoloji.web.tr

[3] http://www.gisdevelopment.net/application/archaeology/general

[4] http://www.geographymatters.com/industries/archaeology/

[5] http://www.pop.psu.edu/gia-core/pdfs/gis_rd_02-32.pdf

[6] http://www.ghccc.msfc.nasa.gov/archaeology

[7] http://www.ccrs.nrcan.gc.ca/resource/tutor/fundam/index_e.php

[8] http://www.crisp.nus.edu.sg/~research/

[9] http://www.csc.noaa.gov/product/nchaz

[10] http://www.geoimage.com.au/geoweb/pdfs/flyers/ALOS_flyer.pdf

[11] http://www.eorc.jaxa.jp/ALOS/

[12] http://www.isprs.org/commission8/workshop_urban/krauss.pdf

[13] www2.jpl.nasa.gov/srtm

[14] http://www.geoconnexion.com/

[15] http://www.3darchaeology.org

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