Google the Earth:

What's Next?


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ABSTRACT

Sensing the Earth has proven to be a tremendously valuable tool for understanding the world around us. Over the last half-century, we have built a sophisticated network of satellites, aircraft, and ground-based remote sensing systems to provide raw information from which we derive and improve our knowledge of the Earth and its phenomena. Through remote sensing, our basic scientific knowledge of the Earth and how it functions has expanded rapidly in the last few decades. Applications of this knowledge, from natural hazard prediction to resource management, have already proven their benefit to society many times over. Today maps and satellite imageries have become an integral part of the developmental process and have also triggered new business opportunities. Maps are essential at all stages of infrastructure development, resource planning and the disaster management cycle. Satellite imagery/data can be used for everything from ground truthing and change detection, to more sophisticated analyses, including feature extraction and natural hazard prediction. As imagery has become more accessible and more affordable in recent years, there is also a growing convergence of imagery and geographic information system (GIS) applications. Geospatial scientists and analysts thus, need to be able to easily access imagery and move seamlessly between GIS and image processing applications to derive the most information possible from them. Technologically, the challenge is to design sensors that exhibit high sensitivity to the parameters of interest while minimizing instrument noise and impacts of other natural variables. The scientific challenge is to develop retrieval algorithms that describe the physical measurement process in sufficient detail, yet are simple enough to allow robust inversion of the remotely sensed signals. Considering the exponential growth of data volumes driven by the rapid progress in sensor and computer technologies in recent years,

the future of remotely sensed data should ideally be in automated data processing, development of robust and transferable algorithms and processing chains that require little or no human intervention. In meeting the above mentioned challenges, some research works have been done at Universiti Putra Malaysia. These works cover all aspects of the remote sensing process, from instrument design, image processing, image analysis to the retrieval of geophysical parameters and their application in natural resources planning and disaster management. Some of the major research efforts include feature extraction from satellite imagery; spatial decision support system for oil spill detection, monitoring and contingency planning; fish forecasting; UAV-based remote imaging and natural disaster management and early warning systems for floods and landslides. This lecture concludes that through remote sensing, our basic scientific knowledge of the Earth and how it functions have expanded rapidly in the last few decades. Applications of this knowledge, from natural hazard prediction to resource management, have already proven to be beneficial to society many times over. As the demand for even faster, better and more temporally and spatially variable information grows dramatically, this lectures answers the question of what remote sensing will be like in the coming decades and the new capabilities and challenges that will emerge.

INTRODUCTION

Satellite pictures of the earth have become commonplace as seen in daily weather reports on television, where regular images taken by geostationary satellites show the weather and various atmospheric phenomena. With online Web-based virtual globes such as Google Earth or Virtual Earth, satellite imagery can be zoomed in on from the full earth disk to detailed views of any place on the earth in a matter of seconds.

What is the first thing most users do in Google Earth? Typically they fly to their homes, navigate around their neighborhoods and perhaps explore potential travel and vacation spots. While this is a wonderful introduction to the power, utility and even pleasure of using Google Earth, increasingly there are much more interesting applications being launched that leverage the power of Google Earth to help the people, animals and plants of our planet.

Google Earth has placed the reality of terrestrial geography within the reach of every individual. Today maps and satellite imagery have become an integral part of the developmental process and have also triggered new business opportunities. The term 'geospatial' is the hot word around the Internet as Internet search companies have come to recognize that information relevant to our everyday lives should be naturally organized and effectively located in a geospatial context. This new geospatial world is revolutionary for both consumers and businesses. People working in the geospatial field will play a central role in this transformation as personal and professional lives are altered by this new technology.

Satellite imagery can be used for everything from ground truthing and change detection, to more sophisticated analyses, including feature extraction and land-use classification. As imagery has become more accessible and more affordable in recent years, there is also a growing convergence of imagery and geographic information systems (GIS) applications. Geospatial scientists and analysts are thus able to easily access imagery and move seamlessly between GIS and image processing applications to derive the most information possible from them.

Data from satellites have exposed great potential in environmental monitoring and resource management capabilities thus increasing the curiosity of researchers and the need to answer questions such as:

- The growth rates of urban areas and how infrastructure development match up with the increasing localized demand for transportation, energy, water and food
- Accurate retrieval of rainfall rates from satellite observations for flood prediction, landslides, mosquito-borne epidemics and other natural hazards
- Deforestation and how it affects biodiversity loss and the global carbon balance
- The rate of change of fresh water resources and wetlands and how to mitigate climate change impacts
- Rise in sea surface temperatures and its effect on global warming
- Measurements of subtle changes in sea surface salinity and its effects on ocean circulation
- Is subsidence threatening buildings in urban areas that had previously been mined?

These and many more questions can only be answered by combining remote sensing and geophysical modeling capabilities in a process-oriented framework. This has become more important than ever since climate change, continued population growth and shrinking natural resources have all become truly global problems requiring, as part of the solution, global monitoring capabilities to better understand how to act locally.

Technologically, the challenge is to design sensors that exhibit high sensitivity to the parameters of interest while minimizing instrument noise and impacts of other natural variables. The scientific challenge is to develop retrieval algorithms that describe the physical measurement process in sufficient detail and yet are simple enough to allow a robust inversion of the remotely sensed signals. Considering the exponential growth of data volumes driven by the rapid progress in sensor and computer technologies in recent years, the future of the remotely sensed data should ideally be in automated data processing, in the development of robust and transferable algorithms and processing chains that require little or no human intervention.

This lecture is designed to cover all aspects of the remote sensing process, from instrument design, image processing, image analysis to the retrieval of geophysical parameters and their application in infrastructure development, natural resources planning and disaster management.

WHY IMAGERY?

The use of remotely sensed data can improve decision making by way of a variety of physical and environmental parameters and information that can be retrieved from them. Some of the benefits of imagery data from satellite remote sensing are the:

- continuous acquisition of data
- up-to-date information (regular revisits to area of study)
- wide coverage and good spectral resolution
- accurate data for information and analysis
- archive of historical data

Overview of Remote Sensing Attributes

Remote sensing is a broad term, encompassing a wide range of sensors that acquire data about the Earth and its environment, and other physical objects and processes. It is a highly interdisciplinary field requiring the combined efforts of electrical engineers, physicists, mathematicians, computer scientists, surveyors, photogrammetry, GIS and the various geoscientists. Some important characteristics of remote sensing are that:

- Sensors operate in different regions of the electromagnetic spectrum (visible, infrared, and microwave regions) and may be mounted on spaceborne, airborne and terrestrial platforms to acquire geophysical data from global to local scales.
- An important, and often the most difficult problem, is to find the correct relation between the remote measurements and the target parameters
- Due to the confounding influence of other natural parameters it may be possible to achieve ambiguous interpretation of the remotely sensed data. The limited number of independent measurements may also mean that an exact solution is unattainable or at the least, impracticable.

These characteristics give rise to some technological and scientific challenges in remote sensing.

So, what exactly is remote sensing? Remote sensing in the simplest form is measuring or acquiring information of an object, place or phenomena without being in direct contact with it. According to the on-line Wikipedia, remote sensing is the small or large-scale acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing device(s) that are wireless, or not in physical or intimate contact with the object (such as by way of aircraft, spacecraft, satellite, UAV, buoy or ship). The basic concept behind optical remote sensing is illustrated in Figure 1.

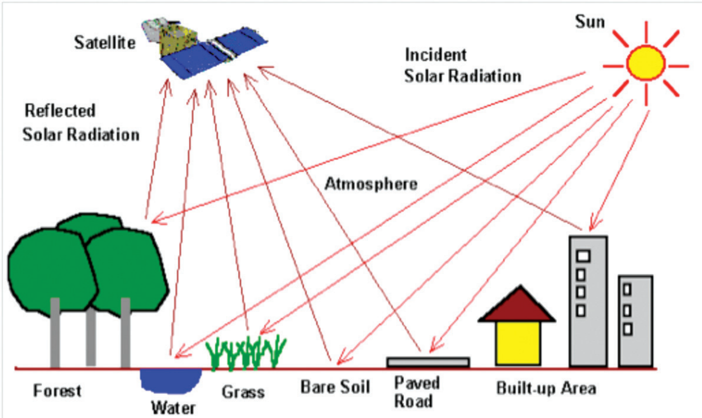

Figure 1 Basic Concept of Remote Sensing

There are two basic types of sensors: passive and active sensors. Passive sensors record radiation reflected from the earth's surface. The source of this radiation must come from *outside* the sensor. In most cases this is solar energy. Due to this energy requirement, passive solar sensors can only capture data during daylight hours. The MAC sensor system on the RazakSat satellite is a passive sensor.

Active sensors are different from passive sensors. Unlike passive sensors, active sensors require the energy source to come from *within* the sensor. 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..

How Sensors Work

Sensors collect and store data about the spectral reflectance of natural features and objects, both of which reflect radiation. This radiation can be quantified on an electromagnetic spectrum.

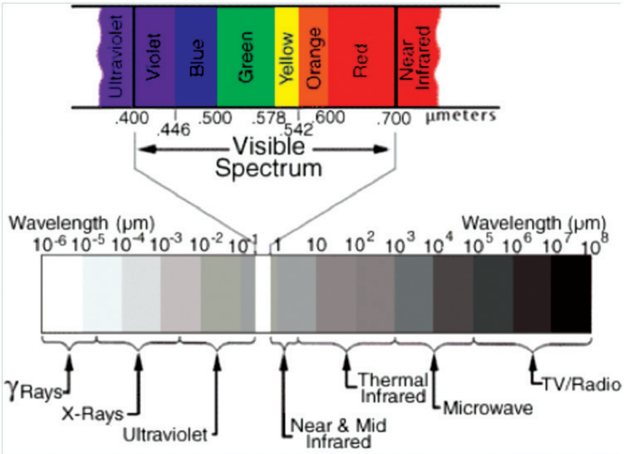

Figure 2 *Electromagnetic Spectrum*

The electromagnetic spectrum is a continuum of electromagnetic energy arranged according to its frequency and wavelength (Figure 2). As the electromagnetic waves are radiated through space, their energy interacts with matter and one of three reactions takes place. The radiation will either be:

1. reflected off the object;
2. absorbed by the object; or
3. transmitted through the object.

The total amount of radiation that strikes an object is referred to as the incident radiation, and is equal to:

incident radiation = reflected radiation + absorbed radiation + transmitted radiation

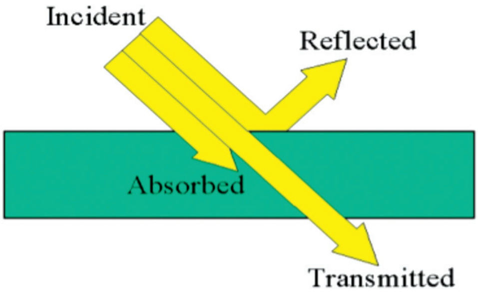

Figure 3 Example of Reflected, Absorbed and Transmitted Radiation

Of these three types of radiation, remote sensing is primarily concerned with reflected radiation. This is the same radiation that causes our eyes to see colors, causes infrared film to record vegetation, and allows radar images of the earth to be created.

Spectral reflectance is the portion of incident radiation that is reflected by a non-transparent surface. The fraction of energy reflected at a particular wavelength varies for different features. Additionally, the reflectance of features varies at different wavelengths. Thus, two features that are indistinguishable in one spectral range may be very different in another portion of the spectrum. This is an essential property of matter that allows for different features to be identified and separated by their spectral signatures.

Imaging Characteristics of Remote Sensing Systems

The success of remote sensing data acquisition requires an understanding of the basic characteristics of remote sensing systems. There are four major resolution characteristics determining the type of geospatial data that can be detected by remote sensing systems. In general, resolution is defined as the ability of an entire remote-sensing system, including lens antennae, display, exposure, processing and other factors, to render a sharply defined image. Resolution of a remote-sensing system comprises of different forms:

i. Spatial Resolution: in terms of the geometric properties of the imaging system, is usually described as the instantaneous field of view (IFOV). The IFOV is defined as the maximum angle of view in which a sensor can effectively detect electro-magnetic energy (Figure 4).

ii. Spectral Resolution: of a remote sensing instrument (sensor) is determined by the band-widths of the Electro-magnetic radiation of the channels used. High spectral resolution, thus, is achieved by narrow bandwidth widths which collectively, are more likely to provide a more accurate spectral signature for discrete objects than broad bandwidth (Figure 5).

iii. Radiometric Resolution: is determined by the number of discrete levels into which signals may be divided.

iv. Temporal Resolution: is related to the repetitive coverage of the ground by the remote-sensing system. The temporal resolution of Landsat 5 is sixteen days.

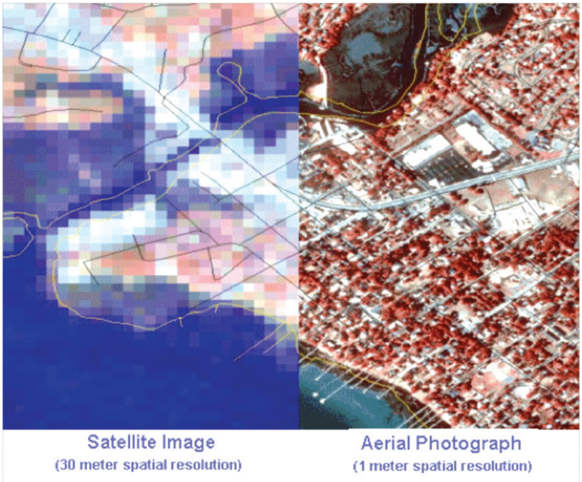

Figure 4 The scale of a project usually determines what type of imagery should be used

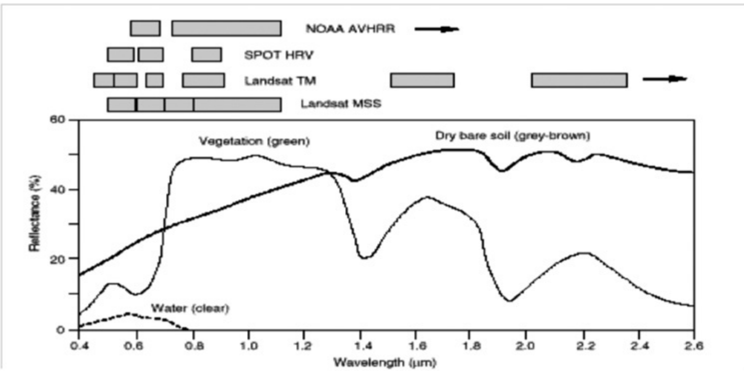

Figure 5 Typical spectral reflectance curves of common earth surface materials in the visible and near-to- mid infrared range. The positions of spectral bands for some remote

Data Acquisition

In this section, we will take a closer look at the characteristics of remote sensing platforms and sensors and the data they collect. In order for a sensor to collect and record energy reflected or emitted from a target or surface, it must reside on a stable platform, removed from the target or surface being observed. Platforms for remote sensors may be situated on the ground, on an aircraft or UAV (or some other platform within the Earth's atmosphere), or on a spacecraft or satellite outside of the Earth's atmosphere.

Ground-based sensors are often used to record detailed information about the surface which is compared with information collected from aircraft or satellite sensors. In some cases, this can be used to better characterize the target which is being imaged by these other sensors, making it possible to better understand the information in the imagery.

Sensors may be placed on a ladder, scaffolding, tall building, crane, etc. Aerial platforms are primarily stable wing aircraft, although helicopters and UAV are occasionally used. Aircraft are often used to collect very detailed images and facilitate the collection of data over virtually any portion of the Earth's surface at any time.

In space, remote sensing is conducted from satellites. Satellites are objects which revolve around the Earth. Satellites include those platforms launched for remote sensing, communication and telemetry (location and navigation) purposes. Due to their orbits, satellites permit repetitive coverage of the Earth's surface on a continuing basis.

Most earth observation satellites, (such as the Landsat, SPOT and IRS series) are in a near polar, sun-synchronous orbit. At altitudes of around 700 - 900km the satellites revolve around the earth in approximately 100 minutes and on each orbit cross a particular line of latitude at the same local (solar) time. This ensures that the satellite can obtain coverage of most of the globe, replicating the coverage typically within 2 - 3 weeks. With sensors which can be pointed sidewards from the orbital path, revisit times with high-resolution frames can be reduced to just a few days. Due to evaporation, the atmosphere normally contains less moisture early in the morning, and so to get a clear picture whilst achieving sufficient solar illumination, satellites often are set to overpass the target area at around 9:30 - 10:30 a.m. local time.

Exceptions to these sun-synchronous orbits include the geostationary meteorological satellites (such as the Meteosat and GOES satellites). These have a 36,000km orbit and rotate around the earth every 24 hours remaining above the same point on the equator, acquiring frequent images showing cloud and atmospheric moisture movements for almost a full hemisphere. Further, satellites required to obtain very high resolution (<2m) images, which often orbit at altitudes of around 200-300 km, are currently not able to operate in a sun-synchronous orbit.

Optical scanning techniques take one of two main forms. A ‘switch-broom’ sensor consists of an oscillating mirror, which directs the reflected light to a few sensors, building up an image by a few lines of picture elements (pixels) at a time. However, more common in modern sensors is the ‘push-broom’ sensor, an array of several thousand CCD-sensors, each recording a single path (column), which are combined to build an image as the satellite orbits the earth.

Whichever scanning method is used, each satellite records an image of constant width but potentially several thousand kilometres in length. Once the data have been received on earth, the imagery is usually split into approximate square sections for distribution. These nominal image sizes typically range from 11x11km (IKONOS, 1m pixels) to 185km x 170km (Landsat-7, 15m and 30m pixels).

The previous sections provide a representative overview of specific systems available for remote sensing in the (predominantly) optical portions of the electromagnetic spectrum. There are however, many other types of less common sensors which are used for remote sensing purposes. We will briefly touch on a few of these other types of sensors. The information is not comprehensive but serves as an introduction to alternative imagery sources and imaging concepts.

Video

Although coarser in spatial resolution than traditional photography or digital imaging, video cameras provide a useful means of acquiring timely and inexpensive data and vocally annotated imagery. Cameras used for video recording measure radiation in the visible, near infrared and sometimes mid-infrared portions of the EM spectrum. The image data are recorded onto cassette and can be viewed immediately.

FLIR

Forward Looking InfraRed (FLIR) systems operate in a similar manner to across-track thermal imaging sensors. However, they provide an oblique rather than nadir perspective of the Earth´s surface. Typically positioned on aircraft or helicopters, and imaging the area ahead of the platform, FLIR systems provide relatively high spatial resolution imaging that can be used for military applications, search and rescue operations, law enforcement and forest fire monitoring.

Laser Fluorosensor

Some targets fluoresce, or emit energy, upon receiving incident energy. This is not a simple reflection of the incident radiation, but rather an absorption of the initial energy, excitation of the molecular components of the target materials, and emission of longer wavelength radiation which is then measured by the sensor. Laser fluorosensors illuminate the target with a specific wavelength of radiation and are capable of detecting multiple wavelengths of fluoresced radiation. This technology has been proven for ocean applications, such as chlorophyll mapping and pollutant detection, particularly for naturally occurring and accidental oil slicks.

Lidar

Lidar is an acronym for LIght Detection And Ranging, an active imaging technology very similar to RADAR (see next paragraph). Pulses of laser light are emitted from the sensor and energy reflected from a target is detected. The time required for the energy to reach the target and return to the sensor determines the distance between the two. Lidar is used effectively for measuring heights of features, such as forest canopy height relative to the ground surface, and water depth relative to the water surface (laser profilometer). Lidar is also used in atmospheric studies to examine the particle content of various layers of the Earth´s atmosphere and acquire air density readings and monitor air currents.

RADAR

RADAR stands for RAdio Detection And Ranging. RADAR systems are active sensors which provide their own source of electromagnetic energy. Active radar sensors, whether airborne or spaceborne, emit microwave radiation in a series of pulses from an antenna, looking obliquely at the surface, perpendicular to the direction of motion. When the energy reaches the target, some of the energy is reflected back towards the sensor. This back scattered microwave radiation is detected, measured and timed. The time required for the energy to travel to the target and return back to the sensor determines the distance or range to the target. By recording the range and magnitude of the energy reflected from all targets, as the system passes by, a two-dimensional image of the surface can be produced. As the RADAR has its own energy source, images can be acquired day or night. Moreover, microwave energy is able to penetrate through clouds and most rain, making it an all-weather sensor.

Synthetic aperture radar (SAR) is another imagery type that consists of information obtained by instruments emitting radio signals rather than passively sensing naturally reflected radiation. A typical radar measures the strength and round-trip time of the microwave signals that are emitted by a radar antenna and reflected off a distant surface or object. The radar antenna alternately transmits and receives pulses at particular microwave wavelengths (in the range 1 cm to 1 m, which corresponds to a frequency range of about 300 MHz to 30 GHz) and polarizations (waves polarized in a single vertical or horizontal plane). Sensors such as ERS 1 and 2 and Radarsat 1 were designed to generate synthetic aperture radar (SAR) images for various applications (Mansor 2000). The ERS data, with its high accuracy positional information, could be used to generate interferograms for high accuracy elevation data. Improvement in interfeometry has also continued with SRTM, TerraSAR-X and TanDEM-X and recently, with sensors such as Envisat

Stereoscopic Data Acquisition

Another important development has been the improved acquisition of stereoscopic data. Sensors such as ASTER, SPOT HRS and ALOS PRISM allow the collection of two or three images within seconds of each other, using fore and aft sensors, whilst agile sensors such as Worldview and GeoEye collected stereo data in a single overpass by changing the pointing direction of the single sensor. The improved high resolution sensors also have multispectral channels, providing colour images which are co-registered with the panchromatic channel. Data fusion allows these channels to be combined, so that the higher resolution and the multispectral characteristics are retained.

Other groups of sensors collect stereoscopic images for generation of digital elevation models (DEMs). Some microwave sensors use synthetic aperture radar technology, which now produce resolution of 1m, interferometrically to produce elevation data and to monitor tectonic movement and subsidence at the millimeter level. These imaging sensors are supported by Global Navigation Satellite Systems (GNSS) which are vital for providing positional information, both for mapping directly and for giving the position of other platforms. The combination of imaging system and positioning system, together with the use of inertial navigation systems, are the driving force behind LiDAR, mobile mapping systems and interferometric synthetic aperture radar systems (IfSAR).

UAV (Unmanned Aerial Vehicle)

The UAV, also called UAS (unmanned aerial system), is an inexpensive airborne instrument platform on which different data capturing sensors can be mounted (optical, Infrared, Radar, Laser, Sonar etc). It opens new possibilities in remote sensing imagery application in areas of research, resource management and environmental surveillance (Mansor 2008). UAV aerial photography is very flexible as it gives complete control over the angle, lighting, and overall appearance of the images being taken. It also has an added. This flexibility allows its use for a variety of projects, among others, aerial surveying and pictures of inaccessible and dangerous places.

Image interpretation

Feature identification and image interpretation of remote sensing imagery involves the identification and/or measurement of various targets in an image in order to extract useful information about them. Targets in remote sensing images may be any feature or object which can be observed in an image, and have the following characteristics: Targets may be a point, line or area feature. This means that they can have any form, from a bus in a parking lot or plane on a runway, to a bridge or roadway, to a large expanse of water or a field.

i. The target must be distinguishable; it must contrast with other features around it in the image.

ii. Recognizing targets is the key to interpretation and information extraction. Observing the differences between targets and their backgrounds involves comparing different targets based on any, or all, of the visual elements of tone, shape, size, pattern, texture, shadow and association.

Data Processing

Digital Image Processing is a collection of techniques for the manipulation of digital images by computers. The raw data received from the imaging sensors on the satellite platforms contain flaws and deficiencies. To overcome these flaws and deficiencies, in order to get the originality of the data, it needs to undergo several stages of processing. This will vary from image to image depending on the type of image format, initial condition of the image and the information of interest and the composition of the image scene. Satellite image processing typically involves image geo-coding, enhancement, filtering and band transformation. Over the years many image processing and analysis techniques have been developed to aid in the interpretation of remotely sensed data and to extract as much information as possible. The choice of techniques or algorithms in image processing depends on the goals of each individual project.

Pre-processing

Pre-processing involves initial processing of the raw satellite data, carried out to correct for any distortion due to the characteristics of the imaging system and imaging conditions. Currently, in most cases pre-processing is carried out by the ground station or image providers before it reaches the end-user, unless the user has certain requirements. Generally, the procedures of pre-processing include radiometric correction to correct for uneven sensor response over the whole image and geometric correction to correct for geometric distortion due to the earth's rotation and other conditions such as oblique viewing. Image may also be transformed to conform to a specific map projection system. For precise geo-referencing, ground control points (GCPs) are used to register the image for accurate geographical location of an area on the image.

Image Enhancement

Image enhancement is the improvement of visual interpretation and visual appearance of the objects in the image through techniques such as grey level stretching to improve the contrast and spatial filtering to enhance the edges. Hazy appearance of a image may be due to the scattering of sunlight by the atmosphere into the field of view of the sensor. This consequently degrades the contrast between different objects in the image.

As an image enhancement technique often drastically alters the original numeric data, it is normally used only for visual (manual) interpretation and not for further numeric analysis. Common enhancements include image reduction, image rectification, image magnification, transect extraction, contrast adjustments, band ratioing, spatial filtering, Fourier transformations, principal component analysis and texture transformation.

Figure 6 (a) shows an original image that has been linear enhanced (b). The hazy appearance as seen in the original image has generally been removed and the contrast between different features has improved.

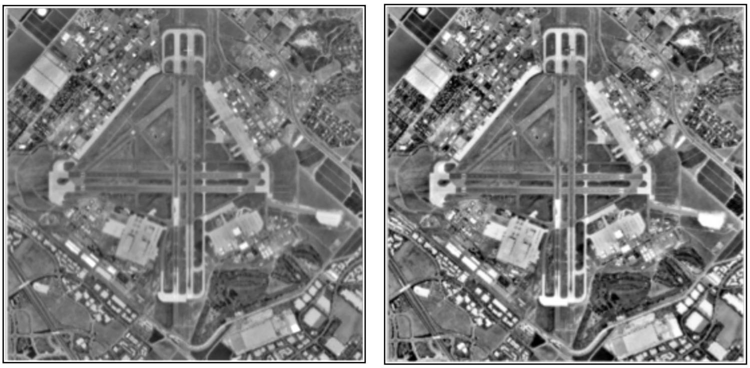

Figure 6 (a) Original image (b) Linear enhanced image

Selecting best band combinations for image display could be time consuming, especially for hyperspectral data. We have developed an algorithm for selecting the best three bands for image visualization (Teoh et al., 2003). This algorithm uses the degree of between-cluster separability in a spectral band and a correlation coefficient to compute the statistical parameter called 'Best Three Bands Combination Index' (BTBCI). The highest value of BTBCI should be the three bands having the most information content. This algorithm was compared with another statistical method called 'Optimum Index Factor' (OIF). Comparison results shown that the band combination of 1, 4 and 5 was found to be the top ranked in the BTBCI and OIF for Landsat TM data. However, the ranking results were significantly different when applied to the MODIS data; where band combination 3, 7 and 20 had top rank in the BTBCI while for OIF it was 8, 22 and 42. The display quality of these two images was different where band combination 3, 7 and 20 was shown to be smoother than the band combination 8, 22 and 42.

Image Filtering

Image filtering is a process by which an image can be enhanced or signal noise removed through modification, warp and mutilation. It is often used to eliminate unwanted frequencies from an input signal or to select a desired frequency in which to display an image. There are a wide range of filters and filter technologies, some of which include spatial filters (average, mean, mode), edge detection filters, Gaussian filter (low pass or band pass filters), high pass filters etc.

Spatial filtering is used to enhance the appearance of an image. Spatial filters are designed to highlight or suppress specific features in an image based on their spatial frequency. Spatial frequency refers to the frequency of the variations in tone that appear in an image. "Rough" textured areas of an image, where the changes in tone are abrupt over a small area, have high spatial frequencies, while "smooth" areas with little variation in tone over several pixels, have low spatial frequencies.

Image Transformation

Image transformations typically involve the manipulation of multiple bands of data, whether from a single multispectral image or from two or more images of the same area acquired at different times (i.e. multi temporal image data). It generate "new" images from two or more sources which highlight particular features or properties of interest, better than the original input images.

Basic image transformations apply simple arithmetic operations to the image data. Image subtraction is often used to identify changes that have occurred between images collected on different dates. This type of image transformation can be useful for mapping changes in urban development around cities and for identifying areas where deforestation is occurring.

Image division or spectral ratioing is one of the most common transforms applied to image data. Image ratioing serves to highlight subtle variations in the spectral responses of various surface covers. By ratioing the data from two different spectral bands, the resultant image enhances variations in the slopes of the spectral reflectance curves between the two different spectral ranges that may otherwise be masked by the pixel brightness variations in each of the bands.

Image Classification

Image classification is the process of creating a meaningful digital thematic map from an image data set. The classes in the map are derived either from known cover types (paddy, soil) or through algorithms that search the data for similar pixels. Once data values are known for the distinct cover types in the image, a computer algorithm can be used to divide the image into regions that correspond to each cover type or *class*. The classified image can be converted into a land use map if the use of each area of land is known.

Classification algorithms are grouped into two types of algorithms: supervised and unsupervised classification. With the supervised classification the analyst identifies pixels of known cover types and then a computer algorithm is used to group all the other pixels into one of those groups. With the unsupervised classification a computer algorithm is used to identify unique clusters of points in data space, which are then interpreted by the analyst as different cover types. The resulting thematic image shows the area covered by each group or class of pixels. This image is usually called a thematic image, or classified image.

Object Oriented Image Classification

The pixel-based classification approaches described in the previous section are based exclusively on the digital number of the pixel itself. Hence, only the spectral information is used for the classification. The conventional pixel-based approach primarily relies on the tone, color or spectral information of individual pixels, but the size, shape, texture, contextual and other type of information inherent in the image scene are ignored or not fully utilized and so its classification accuracy and reliability are often limited. The conventional classification approaches to image analysis produces a characteristic, inconsistent salt-and-pepper classification. This method is far from being capable of extracting objects of interest. It is able to carry out the classification parameter based only on the spectral properties of each band that is available in the image. The object-oriented approach, on the other hand, brings the supervised classification process into a polygon base. It makes the remote sensing data contents manageable by performing the segmentation process. Beyond that, additional information such as criteria, textual or contextual information of the segments can be described in an appropriate way to derive improved classification results. Hence, Object oriented classification output has proved to be more reliable than pixel based classification (Mansor et al., 2008).

Image Compression

A new algorithm for second generation wavelet compression has been proposed for TIN data compression (Pradhan et al., 2006). In various applications for a realistic representation of a terrain, a great number of triangles are needed that ultimately increases the data size. For online GIS interactive programs it has become highly essential to reduce the number of triangles in order to save on storage space. There is therefore a need to visualize terrains at different levels of detail, for example, a region of high interest should be in higher resolution than a region of low or no interest. Wavelet technology provides an efficient approach to achieve this. Using this technology, one can decompose terrain data according to hierarchy. On the other hand, the reduction iof the number of triangles in subsequent levels should not be too small as this could lead to poor representation of the terrain. We have proposed a new computational code for triangulated irregular network (TIN) using Delaunay triangulation methods (Pradhan et al., 2007). The algorithms have proved to be efficient tools in numerical methods such as the finite element method and image processing. Further, second generation wavelet techniques, popularly known as “lifting schemes”, have been applied to compress TIN data. The new interpolation wavelet filter for TIN has been applied in two steps, namely splitting and elevation. In the splitting step, a triangle is divided into several sub-triangles while the elevation step is used to “modify” the point values (point coordinates for geometry) after the splitting. Subsequently, this data set is compressed at the desired locations by using second generation wavelets. The quality of geographical surface representation after use of the proposed technique as compared with the original terrain shows that this method can be used for significant reduction of data set.

INFORMATION FROM IMAGERY

The future of the remotely sensed data should ideally be in automated data processing and the development of robust and transferable algorithms for retrieving biophysical and geophysical parameters. A brief overview of the research work done at UPM is presented.

Land Use and Land Cover

Most traditional pixel-based classification approaches are based exclusively on the digital number of the pixel itself. Hence only the spectral information is used for the classification. As the conventional pixel-based approach primarily relies on the tone, color or spectral information of individual pixels, the size, shape, texture, contextual, and other type of information inherent in the image scene are ignored or not fully utilized. Hence, the classification accuracy and reliability is often limited. The conventional classification approaches to image analysis produce a characteristic, inconsistent salt-and-pepper classification. However, this method is far from being capable of extracting objects of interest. It is able to carry out the classification parameters based only on the spectral properties of each band that is available in the image. On the other hand, the object-oriented approach brings the supervised classification process into a polygon base. It makes the remote sensing data contents manageable by performing the segmentation process. Moreover, additional information such as criteria, textual or contextual information of the segments can be described in an appropriate way to derive improved classification results. Consequently, Object oriented classification output has proved to be more reliable than pixel based classification (Mansor et. al., 2008). Figure 7 shows SPOT-5 satellite image of Prai. Figure 8 is the land use derived for the study area.

Figure 7 SPOT-5 satellite image of Prai

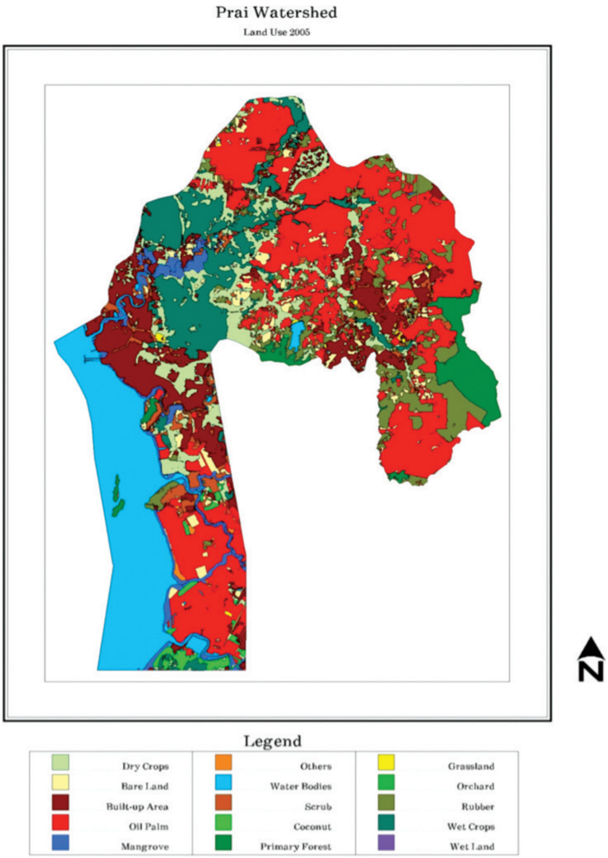

Figure 8 Land use map of Prai

Digital Elevation Model (DEM)

Digital elevation models (DEMs) are currently one of the most important forms of data used for various applications, Conventionally, DEMs are generated from contours, which are derived from aerial photographs using analogue and analytical stereo plotters. The introduction of the soft photogrammetry technique into the market has enabled other sources of data to be used to generate the DEM. This has greatly reduced dependency on aerial photographs as the only source of data as other data such as Spot Stereo and Ikonos high resolution data in optical domain can be used to generate DEMs. However, in the tropics, particularly in Malaysia, the occurrence of cloud cover throughout the year has made this technique unpopular. The recent advent of Synthetic Aperture Radar (SAR) technology has changed the dimension of generating DEMs from conventional stereo photographic techniques to techniques such as Interferometry, radargrammetry and inclinometry. These techniques are becoming more popular due to their capability to penetrate clouds, acquire data irrespective of time and most importantly, the accuracy achievable by the techniques have been proven to be acceptable by many user communities. We have developed an algorithm to generate DEMs based on SAR interferometry (Ku and Mansor 2003). The algorithm was tested using ERS, Radarsat data where the RMS for X, Y and Z were 6.8, 1.5 and 2.8 m respectively.

The use of existing spaceborne SAR data to generate DEMs in the tropical region is not very convincing as yet. It is not because of the limitations of InSAR technology but due to the characteristics of spaceborne data. Single pass data acquisition should ideally be the preference for this part of the world such that have been proven by the Airsar/Topsar Pacrim 1 and 2 missions over Malaysia in 1996 and 2000 respectively and the Shuttle Radar Topographic Mission (SRTM-2000). The possible solution is to have a satellite system with single pass data acquisition for InSAR single image or to develop techniques based on single image. One approach is Shape-From-Shading (SFS) (Clinometry). We have developed an algorithm to generate DEMs using the SFS technique. A new reflectance model for relating the radar SAR backscatter coefficient values to surface normal orientation was developed. Ground truth data in terms of ground control points (GCPs) are used to estimate the coefficients of the reflectance model and an iterative minimization SFS algorithm is implemented using this radar reflectance model to derive relative height measurements.

The relative SFS surface heights were computed using an iterative minimization SFS algorithm that involves the radar reflectance model proposed by Mobarak et al. (2010a) which, is given as:

$$R = \rho \frac{(\cos(\alpha_i))A^2}{(1-(\cos^2(\alpha_i))A^2)^{\frac{3}{2}}} \tag{1}$$

where, α_i is the incidence angle; ρ is the average radar backscatter and A is the illuminated area. The output from the radar SFS model is the relative heights. They are measured relative to the first pixel of the radar subset image which is located in the extreme upper-left corner. Due to the normalization of the reflectance model and the observed image intensity in the Fourier domain, the average heights of some parts of surface terrain could not be recovered. Further, the relative SFS measurements are scaled arbitrarily. Therefore, they need to relate to a specific vertical datum to provide significant results. To get such results, the relative height measurements from SFS were calibrated into absolute surface heights using the new model (Mobaraq et al., 2010b) represented by Equation (2)

$$H = A + Bx + Cy + Dz + E\sigma^\circ + F\beta^\circ \tag{2}$$

Where,

H is the calibrated absolute height values;

A, B, C, D, E, & F are the model coefficients;

x and y are the horizontal coordinates; z is the relative SFS height; σ° is the radar backscatter coefficient; and β° is the radar brightness.

The algorithm was applied to the RADARSAT-1 image. The performance of the algorithm was tested visually and numerically. Validation showed that the algorithm is promising, with an accuracy of RMSE and R^2, 25m and 0.967 respectively (Figure 9).

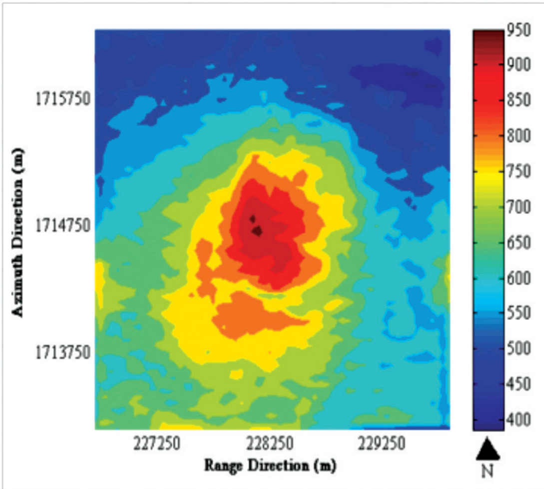

Figure 9 DEM from SFS

Sea Surface Temperature (SST)

AVHRR data has over the years of its existence proved very useful in providing near- real time data for the monitoring and detection of sea surface temperature (SST). The installation of an L-band ground station in ITMA, for the reception of NOAA-AVHRR data, has given the Spatial and Numerical Modeling Laboratory (SNML) the opportunity to develop a near real-time algorithm for estimating SST.

The major advantage of satellite sensors such as AVHRR is the ease and low cost of data acquisition. Inexpensive data, large coverage, daily planetary repeated coverage and composite imagery for sometimes cloud free scenes has made possible a reliable provision of near-real time coverage of large areas.

The algorithm based on radioactive transfer equations was used to extract sea surface temperature. The proposed model (Mansor et al., 2000) is defined as;

$$T_s = a_0 + a_1 T_4 - a_2 T_5 \tag{3}$$

where T_s is sea surface temperature to be calculated, T_4 and T_5 are respectively the brightness temperatures of channel 4 and 5, a_0, a_1 and a_2 are coefficients which depend on the absorption coefficient of the atmosphere, emissivity and total amount of water vapor. The model was tested over AVHRR data (Figure 10) whereby the standard error of the estimated SST is within 1 degK.

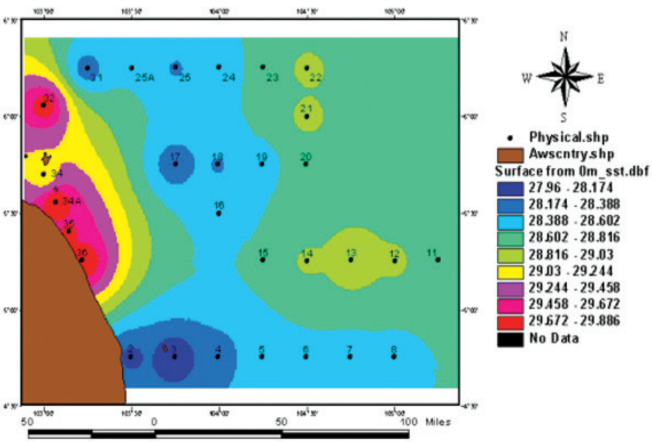

Figure 10 SST of South China Sea

Sea Surface Chlorophyll-a (SSC)

Mansor et al. (2000) have highlighted the need for an operational algorithm to extract chlorophyll-*a* for fish forecasting in Malaysia. No authority has as yet produced a chlorophyll-*a* map or phytoplankton map for Malaysian waters. In view of this problem this research focuses on developing algorithms for estimation of chlorophyll-*a* concentration because currently there is no operational algorithm to extract chlorophyll-*a* for Malaysian waters. The Remote sensing technique is a very useful tool for studying the distribution of chlorophyll-a concentration in a large water body area such as the Exclusive Economic Zone. The data from channel 2, channel 3 and channel 5 of SeaWiFS have been found to be the most suitable to extract the chlorophyll-a concentration. The strong correlation of radiance ratio corresponding to the above channels with in-situ data provided the basis for the development of the equation and constant for the estimated chlorophyll-a concentration in the South China Sea (Asmat et al., 2003). However, the use of satellite remote sensing for mapping chlorophyll-a concentration in the South China Sea is limited by the presence of cloud cover. Despite these disadvantages, satellite data are preferable as compared to field measurements if one's aim is to follow the temporal of phytoplankton over a large area. Saleh et al. (2010b) further developed the SSC algorithm for MODIS data. The equation is as follows:

$$SSC = \exp [a + b * \ln (R)] \quad (4)$$

Where $R = L_w 448 / L_w 551$; a and b are the coefficients.

Sea Surface Salinity

The following equation was developed for extracting SSS from the MODIS data (Salih et al 2010a):

$$SSS=28.1249+0.161925B1-210.996B2+13.9752B3+61.6833B4+147.686B5+1.21641B6-10.981B7+e \quad (5)$$

Where B refers to MODIS bands 1 to 7 and e is obtained from least square estimation of the sampling points. The equation was tested and validated using MODIS data acquired over the Semporna coast, South China Sea. The RMSE is < 1.5 psu.

Sea Surface Current

Much effort has been made to develop algorithms for derivation of wind vectors from SAR images. The wind speed is derived from the normalized radar cross section (NRCS), which is retrieved from the SAR data, using semi empirical C-band models for vertical (VV) polarization.

Mansor and Maiyas (2008) developed the CMODIFR2 model to be applied in the extraction of sea surface wind and current patterns from RADARSAT-1 SAR images. SAR wind field retrieval is a two-step process. The first step is to retrieve wind directions, which is an important input for the second step to retrieve wind speeds. The SAR wind speed retrieval is dependent on the accuracy of wind directions. Doppler shift frequency and nonlinear function were applied to extract the current speed and direction. They concluded that the CMODIFR2 model can be used to extract sea surface wind patterns from RADARSAT-1 SAR images with acceptable accuracy (Figure 11).

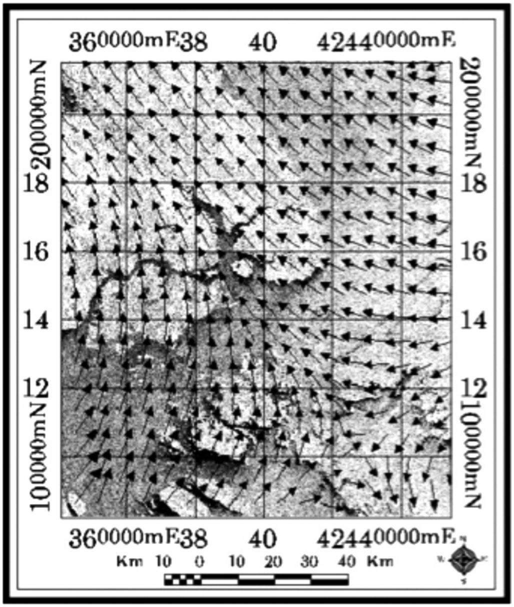

Figure 11 Wind pattern derived using CMODIFR2 wind retrieval model

A robust model has been developed to measure and extract the ocean surface current patterns (velocity and direction) from RadarSat-1 SAR imageries (Mansor and Maayas 2006). The model is as follows:

$$G(x_0,\omega)= H(\omega)e^{i\omega' x_0/V}\int_{-\infty}^{\infty}\exp\left[-\frac{2}{T_s^2}\left(1+\left(\frac{T_s}{T}\right)^2-\frac{ibT_s^2}{4}\right)\tau^2-\frac{4}{T_s}\left(\frac{x_0}{VT_s}+i\frac{\omega' T_s}{4}\right)\tau-\frac{2x_0^2}{V^2T_s^2}\right]d\tau \qquad (6)$$

where x_0 is the location of a point target in the SAR image, T_s is the Gaussian function with width, V is the satellite velocity = 6212m/s, τ is the delay time = $t - x_0 / V$ and $X_0 = vt$, and b is the chirp rate = $2kv^2 / R$

The model was applied to three different from RadarSat-1 SAR image modes (Wide3, HighExtended6, and Standard2). The energy spectra of the surface current, both inshore and offshore, can be estimated. The validation site is located between longitudes 102°50’00” to 103°40’00” East and latitudes 5°25’00” to 5°40’00” North, along the east coast of Kuala Terengganu. The RadarSat-1 SAR modes used in the study were Wide3, High Extended6, and Standard2 modes with accuracy validation (r^2). The validation accuracy (r^2) of the model was 75.3%, 72.6, and 86.3% respectively (Figure 12). These images had been acquired during the period 20-31 March 2005.

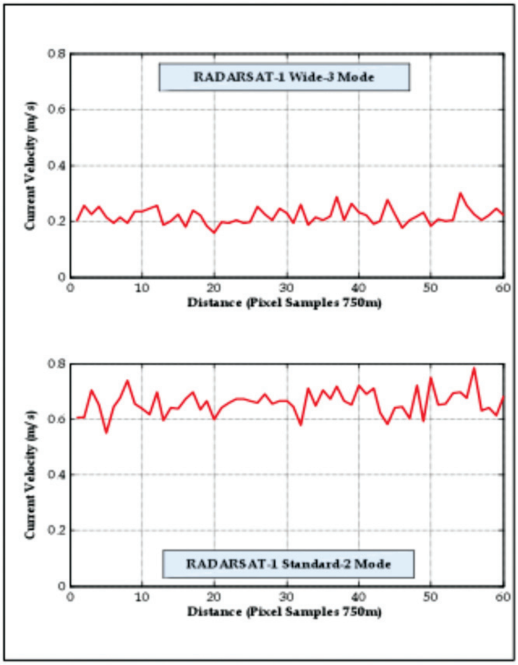

Figure 12 Sea Surface Current Velocity Simulated from RADARSAT-1 SAR Wide-3 and Standard-2 Modes in the Offshore Area

MODELS, MAPS AND MANAGEMENT

Maps are essential at all stages of the infrastructure development, resource planning and disaster management cycle. Satellite imagery can be used for everything from ground truthing and change detection, to more sophisticated analyses, including infrastructure planning and natural hazard prediction. As imagery has become more accessible and more affordable in recent years, there is also growing convergence of imagery and geographic information systems (GIS) applications to derive and describe the physical measurement process in sufficient detail, yet simple enough to allow robust inversion of the remotely sensed signals into thematic maps. These thematic maps are then used as an integral part of the spatial decision support system being developed. In this context convergence of imageries, information, models and maps is very critical. This chapter covers some of the research works done from infrastructure and resource planning to natural and technological hazard management.

Facilities and Asset Management

What is facilities and asset management? Another management initiative or just reworking of good old common sense? We have been managing assets for years, and the financial services world has long been using the term to mean “getting the best return from their investments”. Nowadays, however, it is also being used to describe the professional management of physical infrastructure, of data and information, of people, public image, reputation and other types of assets. Oil companies, power and water utilities and other industries have recognised that despite all their cost-cutting, reorganisation, new technology, productivity and quality initiatives, the picture is fragmented. Inefficiency and conflicting objectives, lack of coordination and missed opportunities are still plentiful.

This is where facilities and asset management methods are needed – to make sure that the jigsaw puzzle is complete and the bits fit together. Facilities and asset management is the set of processes, tools, performance measures and shared understanding that glues the individual improvements or activities together.

In today's campus environment, maintenance managers must be able to accurately track and analyze operating and maintenance costs while taking advantage of opportunities to improve the reliability of facility and operations. Computerized maintenance management systems have become the backbone of such efforts in many facilities. A facilities management system (FMS) provides the capability to document, schedule and monitor the maintenance, repair and project costs associated with facilities and assets. It provides historical records of labour and material expenses on which maintenance and capital improvement budgets and manpower requirements can be based. Properly selected and implemented, the FMS is one of the most powerful tools in any organization. Further, with the proliferation of software options and their implications for other areas of facilities, managers face an even more important decision in selecting the "right" FMS. Selecting the most appropriate FMS must be an organized and precise effort, driven by the goal of implementing a system that will provide effective maintenance planning and history. UPM encountered two main challenges in delivering on the facilities management objectives – getting the people issues right and getting the system issues right.

Figure 13 (below) shows an overlay of linear assets (roadways) and non-linear assets (buildings) on an aerial photograph. This uniform way of visualization, identification and modeling of assets, irrespective of their type, aids in work planning, dispatch and execution.

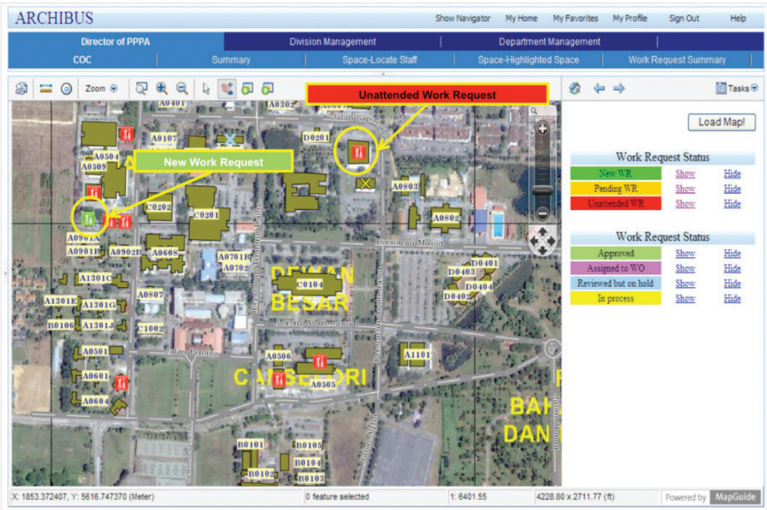

Figure 13 Linear and other assets on a projection map

Natural and Technological Disaster Management

Maps are essential at all stages of the disaster management cycle: prevention, mitigation, preparedness, response and recovery. It is important to undertake a range of activities such as: risk assessment; scenario analysis or analysis of consequences; forecast and projection; dissemination of information; allocation of personnel, equipment and other resources; the ability of relief personnel to reach various affected areas; damage assessment and so on (Mansor et al., 2004).. Maps play a critical role in all these activities. Hazard maps have been recognized as an instrument for disaster management in many countries in recent years. However, most of them are literally only maps indicating dangerous spots and not utilized for disaster reduction. It should also be noted that in many countries hazard maps developed by the national and local authorities are not distributed to the members of the community. The community must be provided with relevant information on hazard maps and on how to utilize them. Most importantly, how effectively hazard maps are used depends on the level of community awareness. The members of the community must be taught on how they can use these maps to understand the potential disasters in their area and to take appropriate counter measures.

In this section, discussion will be mainly confined to the analysis of the role of geoinformation technology in natural and technological disaster management. Satellite imageries and maps describe the locations of features on the Earth's surface. GIS is used to manipulate such data to create useful products and hazard maps while GPS receivers allow relief personnel to locate the affected area or injured residents. Remotely sensed imageries captured from satellite and aircraft provide the first comprehensive picture of an event's impact. Geoinformation tools are useful and indeed essential in all phases of disaster management. Yet it is never easy to persuade authorities or the general public of the need for investment in geoinformation infrastructure when the primary concerns in the immediate aftermath of an event are clearly focused on food, shelter and saving In year 2008 alone, natural disasters affected 214 million people, killed more than 235,000 and cost more than US$190 billion (Rodriguez et al., 2008).

Natural events cannot be prevented, but potential disasters can be 'managed' to minimise loss of life through a four-part cycle of mitigation, preparedness, response and recovery (Table 1).

Table 1 The four-part disaster cycle

- **Mitigation.** Long-term efforts to prevent hazards from becoming disasters or to make them less damaging. These include structural measures such as creating flood levees or reinforcing buildings, as well as non-structural measures such as risk assessment and land-use planning.
- **Preparedness.** Planning for when disaster strikes, including developing communication strategies, early warning systems and stockpiling supplies.
- **Response.** Implementing plans after a disaster. This includes mobilising emergency services, coordinating search and rescue efforts and mapping the extent of the damage.
- **Recovery.** Restoring an area, often through rebuilding and rehabilitation, then returning to mitigation measures.

Many types of satellites are used for earth observation but the area they see, and the frequency of observations varies. Two complementary types are particularly relevant to disaster management. Polar-orbiting satellites fly in a relatively low orbit (often at around 1000km above the ground), providing relatively high spatial resolution. However, they only collect data over the same point once every few days.

Geostationary satellites are positioned at a much higher altitude (about 36,000km). They orbit the Earth at the same speed as the Earth rotates on its axis, in effect remaining stationary above the ground and viewing the whole earth disk below. Their spatial data is much coarser, but is collected at the same point every 15 minutes. Each satellite carries one or more sensors on board that take measurements in different wavelengths. Many are useful for disaster monitoring — thermal sensors spot active fires and infrared sensors can pick up floods and subsurface fires (Mansor et al., 1994).

Landslides

Landslides or mass movements of rock and unconsolidated materials such as soil, mud and volcanic debris, are much more common than is generally perceived by the public. Many are aware of the catastrophic landslides, but few are aware that small slides are of constant concern to those involved in the design and construction business. These professionals can often exacerbate the problem of landsliding through poor planning, design, or construction practices. Frequently, the engineers are also forced into difficult construction or development situations as a result of ignoring the potential landslide hazard. This can be avoided if there is early recognition of the hazard and there is effective consultation between planners and the construction team prior to detailed development planning (Faisal et al., 2008)

Globally, landslides cause approximately 1,000 deaths per year with property damage of about US$4 billion. In Malaysia, landslides posed serious threats to settlements and structures that support transportation and tourism recently, causing considerable damage to highways, waterways and pipelines. Most of these landslides occurred on cut slopes or on embankments alongside roads and highways in mountainous areas while a few landslides occurred near high-rise apartments and in residential areas, causing death to human beings. The recent landslides which occurred near the North Klang Valley Expressway is a good example of the tropical landslides in Malaysia. In tropical countries like Malaysia most landslides are triggered by heavy rainfall.

In this section, the use of remote sensing data along with other tabular and meta data were used to delineate the landslide hazard mapping for Cameron Highlands. Terrain information such as slope, aspect, curvature, distance from drainage, geology, distance from lineament, soil, land cover, Normalized Difference Vegetation

Index (NDVI) and precipitation information have been updated to enable the quantification of landslide causative parameters. The qualitative landslide hazard analysis has been carried out using the map overlying techniques in GIS environment.

Case Study

The study area encompasses part of the districts in the Cameron Highlands which are experiencing rapid development with land clearing for housing estates and hotel/apartments, causing erosion and landslides (Figure 14). Cameron Highlands is located 30 km from Tapah, northwest of Pahang, and is a district in the Pahang state. This area is dominated by a sequence of mountains and hills as part of the Titiwangsa Mountain Range between 1280 and 1830 m above sea level. The study area covers an area of 660 square km and is located near the northern central part of Peninsular Malaysia. It is bounded in the north by Kelantan and to the west by Perak. Annual rainfall is very high, averaging between 2,500 mm to 3,000 mm per year. The area experiences two pronounced wet seasons from September to December and February to May. The maximum rainfall peaks fall between November to December and March to May when many landslides have been recorded along streams scouring the sides of the highlands.

The geology of the Cameron highland consists of mostly quaternary and Devonian granite. Geologically, this area consists of granitic rock with grain size ranging from medium to coarse. This rock is part of the main range granite, aged Late Mesozoic. The granitoid mountain range forms the highland areas with the highest point occuring at Gunung Brinchang (2030 m). The granitoid rock is part of the batholith intrusion, which forms the main range of the Malaysian peninsula. The geomorphology of the area consists of an undulating plateau stretching about 12 km towards the northern part of Peninsular Malaysia. The study area consists generally of high, rugged mountains and minor narrow intermontane riverine alluvial basins. The highlands are cloud-covered nearly throughout the year. The area is also mainly covered by dense tropical forest and some tea plantations, temperate vegetable and flower farms.

The Model

In this study, 1:25,000 scale aerial photographs were used to detect the landslide locations. These photographs were taken during the period 1981 – 2000, and the landslide locations were detected by photo interpretation and verified by fieldwork. Recent landslides were observed in aerial photographs from breaks in the forest canopy, bare soil or other geomorphic characteristics typical of landslide scars, for example, head and side scarps, flow tracks, and soil and debris deposits below a scar. To assemble a database to assess the surface area and number of landslides in the study area, a total of 324 landslides were mapped in a mapped area of 293 km^2.

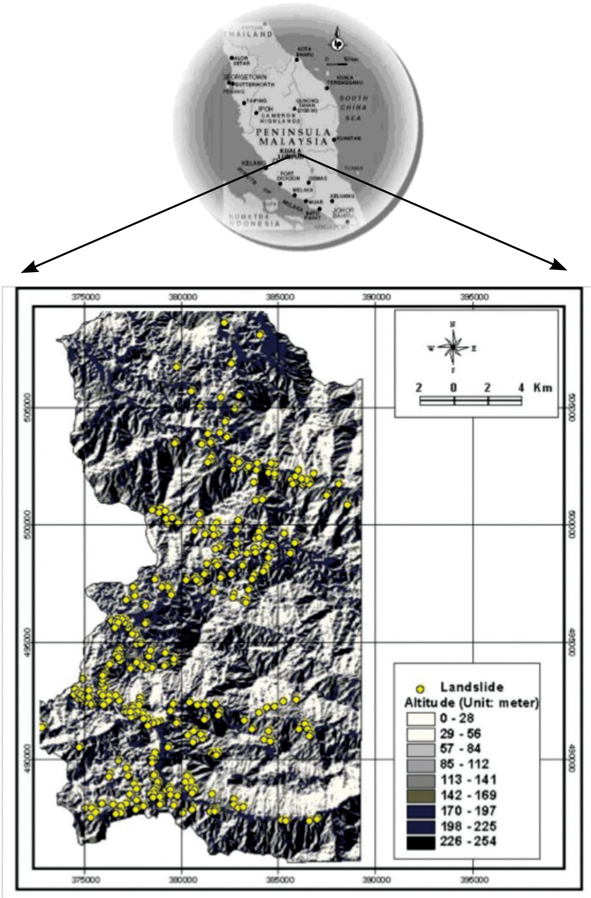

Figure 14 Landslide locations with hill shaded map of study area.

To apply the logistic regression model, a spatial database that considers landslide-related factors was designed and constructed (Pradhan et al., 2008). There were ten factors that were considered in calculating the probability, and the factors were extracted from the constructed spatial database. The factors were transformed into a grid spatial database using the GIS, and landslide-related factors were extracted using the database. A digital elevation model (DEM) was first created from the topographic database. Contour and survey base points that had elevation values from the 1:25,000-scale topographic maps were extracted, and a DEM was constructed with a resolution of 10 m. Using this DEM, the slope angle, slope aspect, and slope curvature were calculated. In the case of the curvature, negative curvatures represent concave, zero curvature represent flat and positive curvatures represents convex. The curvature map was produced using the ESRI routine in Arc View. In addition; the distance from drainage was calculated using the topographic database. The drainage buffer was calculated in 1m intervals. Using the geology database, the lithology was extracted, and the distance from lineament calculated. The lithology maps have been obtained from a 1:63,600-scale geological map from the Mineral and Geosciences Department, Malaysia. Further, lineaments were visually extracted using the SPOT 5 satellite imageries to complement the linear features obtained from the litho map. The lineament buffer was calculated in 1 meter intervals. The lineament buffer was calculated in 10 m intervals. The soil map was obtained from a 1:250,000-scale soil map. Land cover data was classified using a LANDSAT TM image employing an unsupervised classification method and topographic map. The land cover map was classified into six classes, such as Dense Forest area, Barren land, Agriculture, Rubber, Residential area (Concrete), Sparse Forest area and Residential area (Non-concrete), which were extracted for land cover mapping. Finally, the NDVI map was obtained from LANDSAT TM satellite images. The NDVI value was calculated using the formula NDVI = (IR – R) / (IR + R), where the IR value is the infrared portion of the electromagnetic spectrum, and the R-value is the red portion of the electromagnetic spectrum. The NDVI value denotes areas of vegetation in an image. Precipitation data was interpolated using the meteorological station data for the whole of Peninsular Malaysia over the last 20 years.

Subsequently, the calculated and extracted factors were converted to a 10m × 10m grid (ARC/INFO GRID type). Using the logistic regression model, the spatial relationship between landslide-occurrence and factors influencing landslides was assessed. The logistic regression mathematical equation was formulated as shown in equation (7).

$$\begin{aligned} z_n = {} & (0.0655 \times SLOPE) + ASPECT_c + (0.0494 \times CURVATURE) + \\ & (0.0007 \times DRAINAGE) + LITHOLOGY_c + (-0.0004 \times LINEAMENT) + \\ & SOIL_c + LANDCOVER_c + (-0.7563 \times NDVI) + (0.0155 \times PRECIPITATION) - \\ & 64.1220 \end{aligned} \tag{7}$$

(where $SLOPE$ is slope value; $CURVATURE$ is curvature value; $DRAINAGE$ is distance from drainage value, $LINEAMENT$ is distance from Lineament value. NDVI, $ASPECT_C$, $LITHOLOGY_C$, $SOIL_C$, LANDCOVER$_C$ and $PRECIPITATION$ are logistic regression coefficients value listed in Pradhan et al. (2008) and z_n is a parameter).

The Landslide Hazard Map

Finally, the maps were verified and compared using known landslide locations and success rates and ratio areas were calculated for quantitative validation. The hazard map was then classified into 10 equal area classes in GIS. Out of the 10 equal area classes the first 10% was represented as "very high hazardous area" and the next 10% classified as "high hazardous area". Similarly, the remaining 40% of the total equal area was classified as "moderate hazardous area". Finally, the remaining 40% of the area was classified as "non hazardous area". The final classified hazard map is shown in Figure 15.

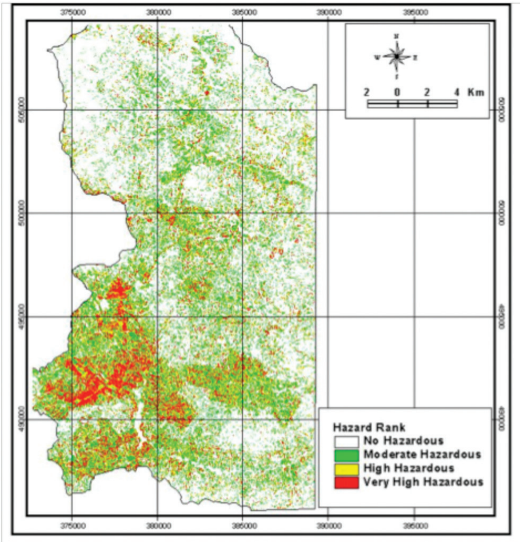

Figure 15 Landslide hazard map based on logistic regression model.

For validation of landslide hazard calculation models, two basic assumptions are needed. One is that landslides are related to spatial information such as topography, soil and land cover, and the other is that future landslides will be triggered by a specific factor such as rainfall. In this study, the two assumptions are satisfied because the landslides were related to the spatial information and the landslides were triggered by heavy rainfall in the study area. The landslide hazard analysis result was validated using known landslide locations. Validation was performed by comparing the known landslide location data with the landslide hazard map. In the case of the logistic regression model used, 90 to 100% (10%) class of the study area where the landslide hazard index had a higher rank could explain 51% of all the landslides. In addition, the 80 to 100% (20%) class of the study area where the landslide hazard index had a higher rank could explain 76% of the landslides. To compare the results quantitatively, the areas under the curve were re-calculated, whereby the total area is 1 which means perfect prediction accuracy. So, the area under a curve can be used to assess the prediction accuracy qualitatively. In the case of the logistic regression model used, the area ratio was 0.8573 and so we could say that the prediction accuracy is 85.73% (Figure 16)

Summary

In the present study, the logistic regression model was applied for the landslide hazard mapping for Cameron highlands. The validation results show that the logistic regression model has predication accuracy of 85.73%. The logistic regression model requires conversion of the data to ASCII or other formats for use in the statistical package, and later re-conversion for incorporation into the GIS database. Moreover, it is difficult to process a large amount of data in the statistical package. In the case of a similar statistical model (discriminant analysis), the factors must have a normal distribution, and in the case of multi-regression analysis, the factors must be numerical. However, for logistical regression, the dependent variable must be input as 0 or 1, therefore the model applies well to landslide occurrence analysis. Recently, landslide hazard mapping has been shown to be of great importance for suitable urban developments. The results shown in this paper can help developers, planners and engineers in slope management and land-use planning. However, one must be careful when using the models for specific site developments. This is because of the scale of the analysis where other slope factors need to be considered. Hence, the models used in the study are considered valid only for generalized planning and assessment purposes.

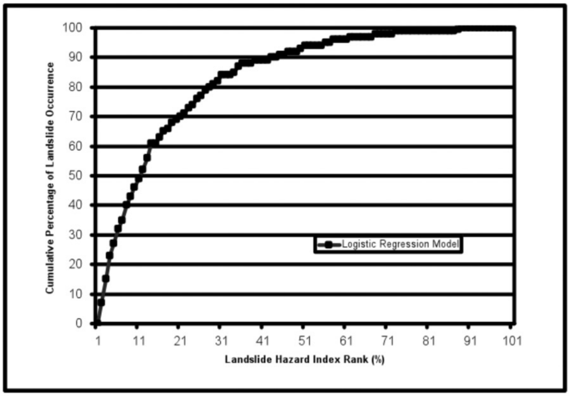

Figure 16 Cumulative frequency diagram showing landslide hazard index rank occurring in cumulative percent of landslide occurrence.

Floods

Floods are the most common of natural hazards that can affect people and infrastructure. They can occur in many ways. Riverine floods, the most prevalent, are due to heavy and prolonged rainfall. Other floods are caused by extremely heavy rainfall occurring over a short period in relatively flat terrain, high tides, excessive runoff and dam failures.

In South East Asian countries such as Malaysia, severe monsoon rainstorms some-times result in flash floods that strike quickly and in most cases without warning. Flooding is usually observed before any warning and usually people and properties are affected before any warnings can be issued. The consequences of these floods are economic loss, social disruption and sometimes loss of lives. Severe monsoon rainfalls are the most destructive natural disasters affecting Malaysia in respect of cost, damage to property and the extent of areas affected**.** The devastating tsunami of 26th December 2004 that caused huge causalities in some South East

Asian countries, including Malaysia, might make this statement arguable, but since the occurrence of tsunamis of this magnitude are rare and the chances of such occurrences are once in 50 years or more, monsoon floods still stand out as the most frequent and destructive natural disaster affecting Malaysia.

The basic cause of flooding in Malaysia is the incidence of heavy monsoon rainfall and the resulting large concentration of run-off, which exceeds the capacities of river systems (Ho *et al.*, 2002). Rapid urbanization within river catchments in recent years have also served to compound the problem with higher run-offs and deteriorating river capacity that increased flood frequency and magnitude. Various flood forecasting models and warning systems have been applied in Malaysia but they have proved inadequate due to their inability to predict impending floods and reduce the consequent economic costs of damage to lives and properties

Accurate and timely forecast of severe monsoon storms and early warning of floods are instrumental to the reduction of flood impacts. The damage caused by floods are generally associated with wind, storm surge and flooding. Forecasting of impending floods requires adequate hydro-meteorological information such as real-time rainfall, quantitative precipitation forecasts (QPF) and the cyclone landfall location. In the absence of quantitative estimates of local rainfall rates before the actual rainfall event, it is practical to get local precipitation data from satellites. Data from satellites can be processed for mesoscale rainfall as input into hydrological models through data assimilation for improved analysis and the provision of early flood warnings in advance of the flood event. Hence, close interaction of spatial meteorological technologies in the form of severe weather forecasting and hydrological modeling is important for improvement of operational flood forecasting and early warning and the consequent reduction in the impact of floods.

Ideally synoptic data are used to provide information on runoff and basin responses for flood forecasting, mostly with short lead times. However for a flood forecast to be really effective, a long lead time of forecast is necessary to provide enough time for contingencies. This can only be provided by meteorological satellite data processed to retrieve cloud information, determine local rainfall and predict flood disaster. Satellite remote sensing methods that are appropriate for operational weather forecasting rely on empirical relationships of thermal infra-red (TIR) and passive microwave imagery and/or rain gage GTS data (Xie and Arkin 1997). However, their success is limited by the indirect nature of the relationship of the observations to precipitation and the fact that they require calibration using gage data. The development of a flood early warning system therefore requires the integration of remote sensing, GIS and hydrological models for provision, monitoring and prediction (Billa et al., 2004).

Why Remote Sensing

Generally, remote sensing techniques are used to measure and monitor the areal extent of the flooded areas, to efficiently target rescue efforts and to provide quantifiable estimates of the amount of land and infrastructure affected. Then again remote sensing is also used for weather monitoring and quantitative precipitation forecasting to retrieve rainfall estimates. Incorporating remotely sensed data into a GIS allows quick calculations and assessments of water levels, damage and areas facing potential flood danger. Users of this type of data include flood forecast agencies, hydropower companies, conservation authorities, city planning and emergency response departments and insurance companies (for flood compensation). The identification and mapping of flood plains, abandoned river channels and meanders are important for planning and transportation routing.

AVHRR data of severe monsoon weather and of varying monsoon cloud formation can provide an understanding of cloud characteristics and rain bearing tropical storms. AVHRR data is preferred for this study because of the easy acquisition, relatively high spatial resolution, cost effectiveness and its ability for automated geometric correction when compared to GOES and GMS data. It also has a better spectral resolution of five channels compared to the three of other meteorological satellite data. NOAA data has relatively high temporal resolution of not more than 6 hours daily. This is however less frequent when compared to the hourly reception of GMS and GEOS data. The challenges are to utilize pre real-time or the earliest AVHRR data cloud observations together with a suitably developed QPF model to improve short-range severe monsoon weather forecasts as input for “Nowcasting”, where nowcasting is defined as flood forecasting in the approximate range of 0-9 hours from observation time.

Flood Early Warning System

The conceptual design of the proposed flood early warning system can be found in Billa et al. (2004). It incorporates meteorological satellite image processing for mesoscale rainfall using pre real–time NOAA-AVHRR data whereby Grid based rainfall intensity is developed as input for flood forecasting.

The second part of the system is a MIKE 11 NAM rainfall-runoff (RR) and a one-dimensional hydrodynamic modeling process for rainfall-runoff, discharge and water level simulation. Various hydrographs are developed from the modeling process. As a part of the MIKE 11 hydrological system the RR model is used for automatic system calibration and also for the simulation of rainfall runoff based on a carefully prepared river basin model.

Part three of the system is the platform for hydrological GIS development. The river basin and catchment delineation are performed here using spatial modeling techniques and tools in GIS. Apart from the collection, preparation and storage of hydrological data such as land cover, contour, settlement and other flood data, the basin surface digital elevation model (DEM) and the river channel geometry are developed in this section using 3D modeling techniques and manipulations of the integrated GIS model. The results of the runoff and hydrodynamic simulation are imported and coupled with the DEM for flood mapping. The flood mapping process is based on the expected precipitation over the basin and sub-watersheds and also on the assumption that floodwater follows the physical constrains of the terrain as it rises. Settlement and critical facilities are overlaid to assess the extent of the flood in relation to these data and a resulting inundation map generated.

Case study : Langat River Basin

The system was tested on the Langat river basin based on an enactment of the severe flood event of 27th September 2000. The Langat watershed area is to the southeast of Selangor state and approximately 27 km to the south east of Kuala Lumpur. The basin area is situated within latitudes 101° 43'E to 101° 58'E and longitudes 02° 59'N to 03° 17'N. It falls under the administrative district of Hulu Langat in the eastern part of the Malaysian peninsula. It is bordered to the south by the district of Sepang and in the west by Kuala Lumpur. Upper Langat area has two major dams, the Langat dam located on the Lui tributary and the Semenyih dam on the Semenyih tributary. These dams, together with the upper Langat catchment area, make up one of the important domestic water supply sources for the approximately 1.9 million population of Kuala Lumpur and the surrounding areas (Wong *et al*., 2002).

Rainfall Estimates Based on Reflectance and Brightness Temperature (T_B)

Empirical studies over the years have established that cloud top temperatures less than 235°K in the tropics generally produce stratiform rainfall at the rate of 3 mm/hr (Arkin and Meisner, 1987). AVHRR data for daytime pass was processed for cloud top reflectance and brightness temperature (T_B). The multi-spectral channels provided by the AVHRR data proved useful in this processing. Raw digital numbers (DN) of channels 1 and 2 of the data in level 1B-format were converted to channel top of atmosphere (TOA) reflectance and thermal channels 4 and 5 to radiance .The tests for reflectance and T_B are shown in Figures 17 (a) and (b) respectively. The values of reflectance are graphically displayed on a color scheme ranging from pink to blue as shown in the processed image, while the processed T_B of channel 4 is shown on the scheme of high T_B in yellow and low T_B in pink.

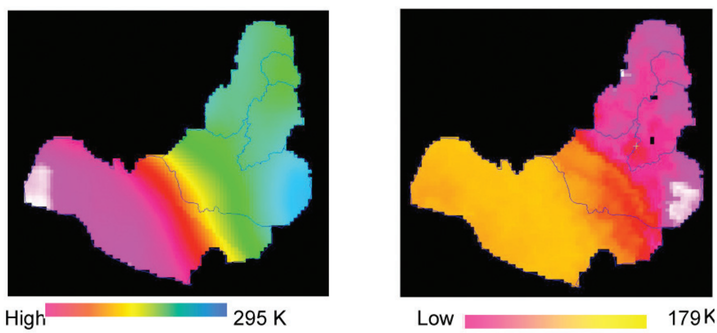

Figure 17 (a) Reflectance (*Refl*) (b) T_B [°K] of Langat river basin

High Cloud Classification and Screening for Non-precipitating Cloud

The AVHRR data was further investigated to establish cloud base height using the combination of channels 1, 2 and 4 and visual interpretation techniques. A supervised classification was performed using the nearest neighbor sampling method to discriminate clouds into high, middle and low clouds heights. This process is important so as to delineate and isolate the higher most clouds for further processing. The high cloud classification was used as the basis for a zonal mean cloud-screening test. The screening for non-precipitation cirrus cloud is performed based on an established empirical discrimination of thin cirrus temperature on a slope plane (Adler and Negri, 1988), where the local minima in the T_B are sought and screened to eliminate thin, non-precipitating cirrus.

Clouds with temperature below 235 ^oK threshold values were taken as indication of instantaneous rainfall. At this temperature, high clouds begin to condense and precipitate. The grid based rainfall and dimensions of rain bearing cloud pixels were measured after a mask had been applied to scale the rainfall model for the Langat basin and catchment level. Rainfall intensity was determined by K-means classification that grouped cloud pixels with T_B below the established threshold into mean clusters. Rainfall rates were assigned to the K-means classes to show intensity (Figure 18) based on the assumption that every rainfall pixel has a beginning unit rain-rate of 3mm/hr, which from empirical studies is appropriate for tropical precipitation over +/-3^o areas around the equator. The mean clusters were assigned rain rate values from 3-12 mm/hr depending on how low the T_B of the cluster is below the 235 ^oK. The total cold cloud cover and the portion of the catchment covered by cloud pixels determine rainfall coverage and the intensity.

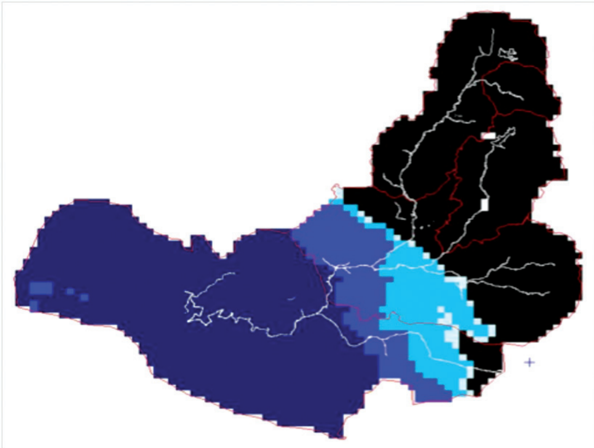

Figure 18 Rainfall intensity based on K-mean classes

Rainfall-Runoff and Hydrodynamic Modeling

Rainfall runoff is performed based on the NAM (RR) model which is part of the MIKE11 River modelling system. It is one of the lumped conceptual models widely applied in hydrological modelling for simulating the rainfall-runoff processes at catchment scale. As the parameters of the model cannot generally be determined directly from the catchment characteristics, the parameter values must sometimes be estimated by calibration against observed data.

The hydrodynamic (HD) simulation in MIKE11 is based on an efficient numerical solution of a complete non-linear St. Venant equation for the 1-D flow. The systems network editor assists in the schematization of the river system and flood plain as a system of inter–connecting branches. The flood level and discharges are calculated at specific points along the branches as a function of time to describe the passage of the flood flow through the model domain.

Rainfall Runoff (RR) Simulation

The rainfall-runoff simulation involves preparation of the Langat River Basin parameters using the MIKE 11 basin work module. The Basin was delineated into main sub-catchments using a registered topographical map. The mean area rainfall distribution was computed and generated based on Theissen's polygon. Rainfall runoff simulation was carried out using the NAM lumped distributed model and results generated graphically in different runoff hydrographs. The model is appropriately calibrated for the basin to ensure good agreement between the observed and simulated data. Two sets of data were used in the rainfall-runoff modeling process to ensure good comparison. The calibration included in the model is shown in:

1. Observed hourly data of rainfall and discharge of the flood event of 27 Sept. to 08 Oct. 2000 (Figure 19).
2. Computed rainfall data based on the developed QPF model by using hourly GMS data for the same flood event of 27 Sept. to 08 Oct. 2000 (Figure 20).

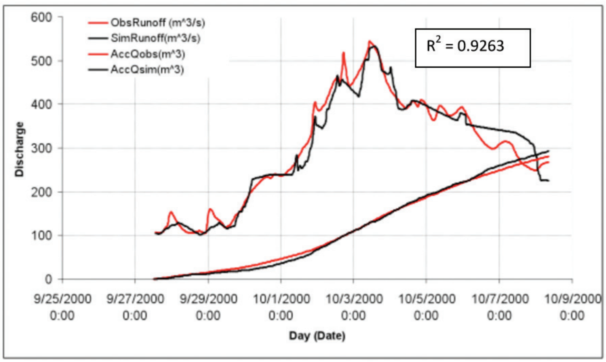

Figure 19 Rainfall-Runoff and Accumulated Discharge (Calibration for Kajang Catchment Based on Observed Data)

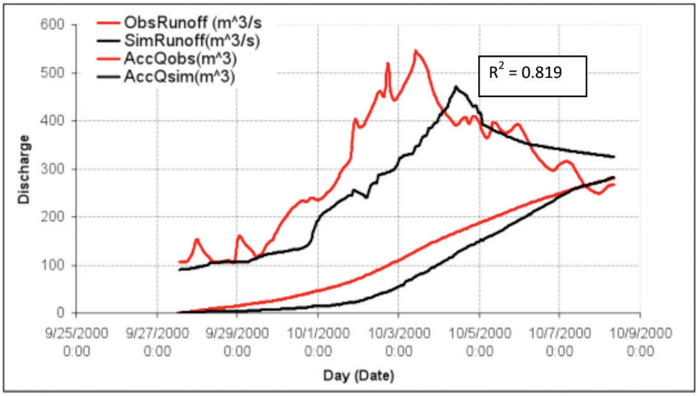

Figure 20 Rainfall-Runoff and Accumulated Discharge (Calibration for Kajang Catchment Based on QPF Rainfall)

Hydrodynamic (HD) Simulation

Hydrodynamic simulation involved the development of the Langat river network model and linking all tributaries in MIKE 11. The river and tributaries cross sections were also developed (Figure 21). Boundary conditions were prepared and entered for both the upper and lower ends of the river section. Overall, 22 rivers and sub river cross-sections were entered for the Langat river basin model. Hourly water levels and discharge data collected were prepared in a compatible MIKE 11 time series format as input to an open boundary type. Observed hourly water levels and discharge data of the flood event were used in the HD simulation.

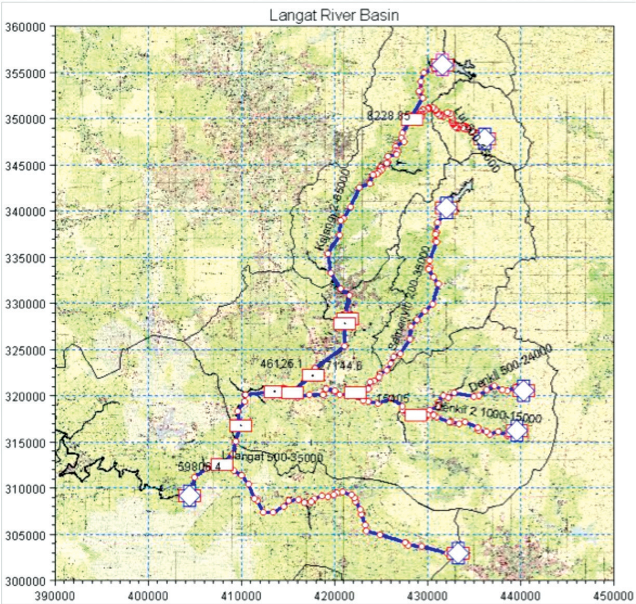

Figure 21 Integrated Langat River Model

Hydrological GIS and Flood Mapping

The hydrological GIS was developed using an integrated MIKE 11 GIS in ArcView 3.2 GIS environment. This allowed the easy importation of MIKE11 calibrated results to be combined with the developed Langat Basin DEM for flood map development. The data developed in the GIS included the road network, river network, settlement, contours for surface terrain development and past flood data point coordinates of flood locations in the flood event. The generation of flood inundation maps is an essential part of flood forecasting and early warning systems. The integrated MIKE 11 GIS provided the essential platform for operational purposes of the early warning process. The basin DEM was imported as a grid file to the flood management module (FM), where it was integrated with the rainfall-runoff and hydrodynamic results of the hydrological modeling.

In the FM module the DEM provides an understanding of the surface elevation of the study area from which flood depth can be extrapolated, whilst runoff and hydrodynamic results provide the automated rainfall-runoff process and flood distribution modeling. Settlement data and other critical facilities were overlaid to visualize and assess the impact of the given flood period. Other ancillary information such as flood extent and depth were deduced from the flood map to facilitate flood impact assessment and contingency planning.

Figure 22 shows the resulting flood area map for the Langat River basin for the simulation period. Buildings and settlement features were generated in the DEM to determine the extent of the flooding. The flood map produced forms the basis for early flood warning in areas likely to be inundated within a given catchment area.

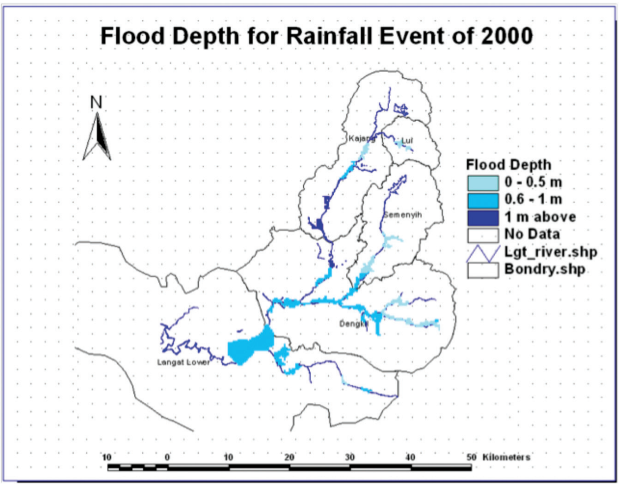

Figure 22 Flood Areas for the Simulation Period

Summary

A comparison of runoff hydrographs generated from the observed rainfall with QPF estimated rainfall showed a high coefficient of determination of R2 = 0.9028. In using rainfall intensity range of 3 - 12 mm/hr, the QPF model was able to replicate the flooding of the storm of 27 September to 08 October 2000, within comparable extent. Using the NAM RR model with suitable calibration coefficients, rainfall-runoff simulation was performed to establish the coefficient of determination (R^2) for both observed and QPF generated rainfall. The runoff hydrograph of the observed data showed $R^2 = 0.896$ between observed and simulated rainfall whilst the hydrograph for QPF generated rainfall showed $R^2 = 0.850$. Although observed rainfall is not as exact as estimated rainfall, both showed comparable flood area coverage in the flood simulation for the flood event. Flood maps generated before an actual flood storm are useful early warning tools for flood emergency and contingency planning. Certain factors can however impact the accuracy of flood maps, such as, the quality of elevation data used in the DEM development, detailed river cross-section and flood plain data and the distribution of rainfall data in the modeling process (Billa et al., 2006).

Forest Fire

Satellite images such as the Landsat Thematic Mapper, SPOT and ERS-SAR combined with low-resolution satellite images such as NOAA-AVHRR and MODIS have been used operationally to monitor forest fires. Remote sensed images also offer capabilities for detecting new wildfire starts, monitoring ongoing active wildfires, and, in conjunction with fire-weather forecasts, providing an early warning tool for escalating, extreme wildfire events (Mansor 2009).

Forest fire and the resultant smoke-haze are increasing in intensity and recurring periodically. Most of the forest fires reported in Malaysia occurred in degraded or logged-over peat swamp forests, both in the east and west coasts of Peninsular Malaysia and the coasts of Sabah and Sarawak. One of the important aspects in eliminating forest fires is the prediction of potential fire hazard areas by preparing the fire hazard maps that can be derived from GIS-based modeling. Fatal damage by forest fire could be reduced if there is suitable prediction and rapid provision against forest fire with the usage of GIS, remote sensing technology and computer modeling.

Forest Fire Detection

Fire detection using remote sensing techniques is not a particularly difficult task except for the effectiveness of the sensor used in relation with the minimum size detected and according to the fire's effective temperature. The study of forest fires through remote sensing techniques has been limited to the cartography of burned areas in cases where real time work is required, and to the assessment of the spreading risk when being operative is required. On the other hand, fire detection is a necessity which will not be solved until geostationary satellites prove their capability to detect small fires and show their usefulness in providing early alert warnings, which will be really difficult considering the difficulty of building high spatial resolution thermal sensors. The most relevant conclusion with respect to the current use of spatial sensors for fire detection is that so far it has been used only for the elaboration of fire occurrence mapping and to obtain statistical results.

With respect to the sensors used to carry out fire detection, the most important one without doubt has been the NOAA-AVHRR sensor, thanks to its higher time resolution and to the type of sensors it has.

MODIS produces global fire maps that show active fires over the past ten days (see Figure 23). This active fire mapping system is used by a wide array of fire monitoring programmes, including Sentinel Asia, the Global Fire Monitoring Center and the regional visualisation and monitoring system, SERVIR, that covers Latin America and the Caribbean.

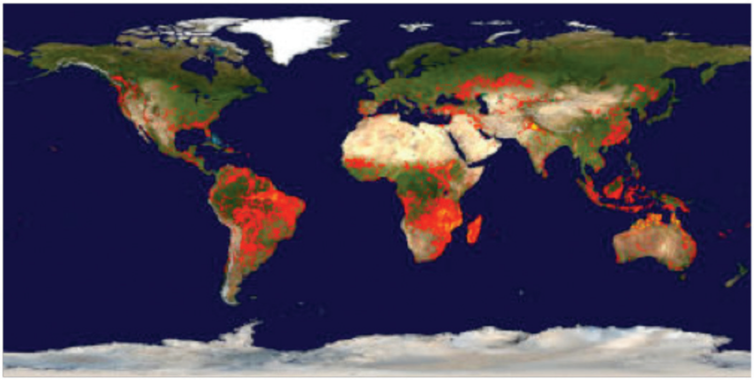

Figure 23 MODIS global fire map 9–18 August, 2009

Forest Fire Hazard Map

Millions of dollars are spent annually on protecting life and property, timber, recreational areas and valuable wildlife habitats. The need for accurate and timely information is crucial for safety and resource protection. There are at least two factors that have to be taken into account in estimating how large the problem of forest fires actually is. First is the number of forest fires. However, the number of forest fires gives us only limited knowledge. Hence, secondly, it is necessary to know how large the total area burned in forest fires year by year is. When these two factors are combines the average size of a fire can be estimated. These two factors indicate how large the problem is and how our system, consisting of measures for prevention, detection and extinguishing, should work. The operational use of satellite data and GIS for forest fire management has four aspects: fire hazard prediction; fire monitoring; inventory of fire damage to forests and assessment of losses; monitoring of recultivation and reforestation efforts. In general, there are two kinds of decision aids required in fire management. The first is a predictive model to identify potential fire problems that may occur, and the second is an operational decision-aid tool (or action plan) to reduce or prevent the impact of serious fire situations.

It is impossible to control nature but is possible to map forest fire risk zones and thereby minimise the frequency of fires. Various fire hazard models and techniques have been developed, that explore the dynamic and static factors for model variables in a bid to provide information on fire susceptibility and the potential area that will be affected.

In Malaysia, an application of Remote Sensing and GIS for forest fire prevention has been attempted by Patah *et al*., (2002), and Pradhan & Arsad (2006). Patah *et al*., (2002) had developed a model using the integration of remote sensing and GIS to produce Fire Risk Index (FRI) maps which could be modified interactively with changing weather conditions. The Forest Canopy Density (FCD) model was applied to the satellite imagery to better differentiate forest fuel types from other ground vegetative fuel types as well as to estimate the percentage of canopy density. The computation is based on four indices – Advanced Vegetative Index (AVI); Bare Soil Index(SBI); Shadow Index (SI) and Temperature Index (TI). FRI maps are relevant for fire management - prevention and suppression. It can help the relevant authority to design regional fire defense plans, which include fuel management practices in drought conditions and design of firebreaks and watch-tower location for Fire Disaster Preparedness.

The Model

A GIS-grid-based fire hazard model was developed to determine the level of severity of wildfire hazard zones in terms of mapping vulnerability to wildfire by assessing the relative importance between wildfire factors and the location of fire ignition (Setiawan, *et al*., 2004). A spatially weighted index model was used to develop the fire hazard model as follows:

$$H = 0:432V + 0:289PR + 0:135A + 0:108S + 0:045E \quad (8)$$

where V, PR, A, S and E are coefficients applied to vegetation, proximity to roads, aspect, slope and elevation.

Combining elevation, dangerous topographic features, slope, aspect and fuel type into one raster data set accurately classifies the danger of forest fire hazards in the area. After the probability grid map was created, a final fire hazard assessment map was generated by multiplying all of the scoring factors with the weighting value derived from the AHP method, as shown in the above equation.

Pekan District in southern Pahang, Malaysia was selected for this study because it faces an annual forest fire problem. The total area is about 83,992 ha, most of which is covered by peat swamp forest (85,218.41 ha or 46.21 percent), with the rest being wetland (50,519.54 ha or 27.39 percent), arable land (22,395.58 ha or 12.14 percent), lowland forest (20,467.96 ha or 11.10 percent) and mangrove forest (4,108 ha or 2.23 percent). At the beginning of July 1997 this area was seriously affected by a dense haze arising from local wildfires in the peat swamp forest. There were about ten reported hot spots of wildfire occurrence in the study area during that time. Wildfire destroyed a PSF area totaling approximately 1,600 ha.

A mosaic Landsat TM scene was used to extract land use parameters of the study area. A triangle irregular network was generated from the digitized topographic map to produce a slope risk map, an aspect risk map and an elevation risk map. Potential of peat swamp forest fire hazard areas were identified and mapped by integrating GIS-grid-based and multi-criteria analysis to provide valuable information about the areas most likely to be affected by fire in the Pekan District, south of Pahang, Malaysia.

Fire-causing factors such as land use, road network, slope, aspect and elevation data were used in this application. Spatial analysis was applied to reclassify and overlay all grid hazard maps to produce a final peat swamp forest fire hazard map. The final fire hazard map is displayed in Figure 24. The final map of the fire hazard zone showed that about 49,678 ha or 27 percent of the total area is categorized as facing very high fire risk, at 10.76, 41.73 and 20.51 percent, respectively, being in the categories of high, moderate and low risk.

To validate the model, the actual fire occurrence map was compared with the fire hazard zone area derived from the model. The results show that most of the actual fire spots are located in very high and high fire risk zones identified by the model (Setiawan, *et al*., 2004). Comparison of the predicted fire hazard zone map and the map showing actual occurrence of hot spots recorded in 1997 in the study area (Figure 25), showed that most of the actual hot spots are located in areas categorized by the model as being very high and high fire risk zones. It can be concluded that the model provides valuable information about the areas most likely to be affected by fire.

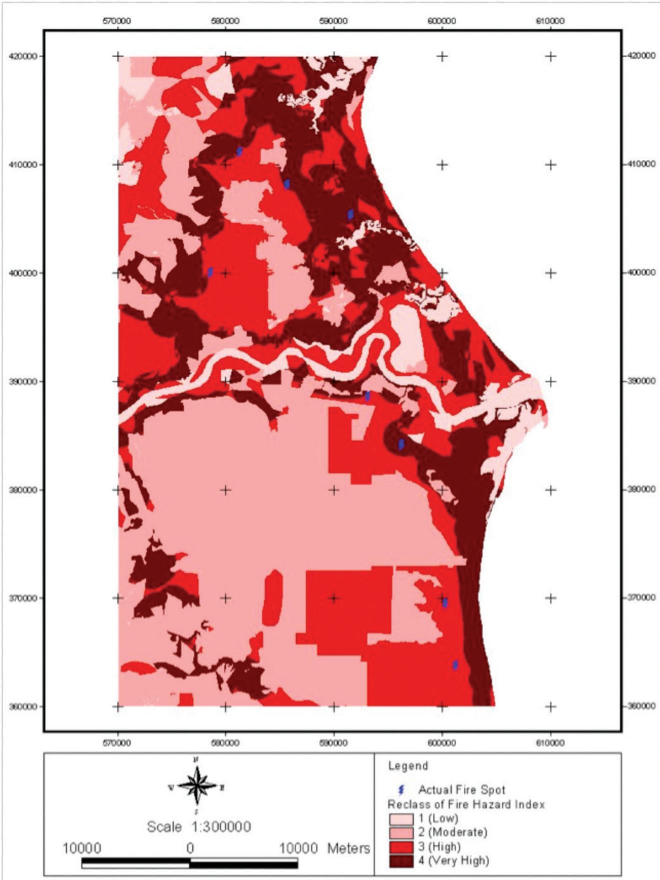

Figure 24 Potential Fire Hazard Map

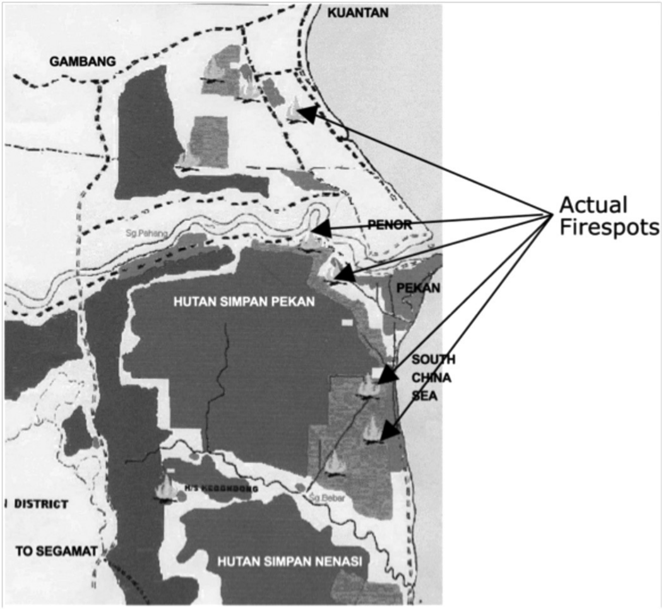

Figure 25 Actual fire spots in the study area, 1997

Geohazard Sinkhole Map

Subsurface geological fractures in karst terrain are often associated with unpredictable environmental and geotechnical engineering problems. This requires precise mapping and an understanding of the distribution of geological fractures on multi-scales. To extract and investigate surface and subsurface geological fractures on such multi-scales, we can use VNIR or SAR imageries (Samy et al., 2009). The integration of visual interpretation and topographical fabric algorithm is capable of extraction and spatial correlation of subsurface geological fractures. This method was applied to the Kuala Lumpur and Ipoh limestone bedrock in Malaysia, by focusing on the adjacent mountainous areas and the geometries and bathymetries of ex-opencast mining ponds. The spatial correlation of the extracted surface geological fractures was clarified by rose diagrams, semivariogram models and a confusion matrix. Spatial correlation shows that the Malaysian peninsular, surface and subsurface geological fractures and the geometry of ex-opencast mining ponds share similar trends. The results obtained using this methodology are compared to the subsurface geological fractures reported by means of geophysical survey and field investigation. This proposed method may be useful for mapping geological fractures in areas of high soil moisture where geophysical survey is difficult and/or not available and is also highly applicable in other parts of Malaysia or south east Asia, permitting better understanding of the geotectonics and geotechnical engineering setting of the study area.

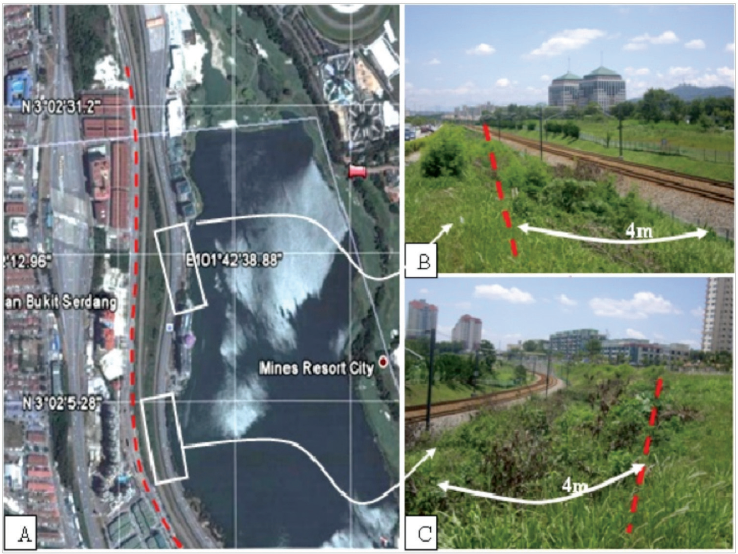

Figure 26 Flank geometry (zigzag pattern) and bathymetry of ex-opencast mining ponds (A), cut slopes (slope breaks or fault displacements, C) and vegetation stress (B) are good sources of geological information for subsurface fracture extraction and analysis

Geostatistical analysis was for investigation of the nature of spatial variations of karst terrain using the GIS (Omar et al., 2010).

The study focuses on using aerial photography for the detection of changes and effects of mining on geomorphology. In addition, the distinctive surface topography of the karst landscapes can be characterized in order to compare them with non-karst landscapes, and to determine geological and/or climatic conditions that are responsible for the observed terrain of the Kinta Valley Limestone formation in Perak, Malaysia. Geostatistical analyses of the karstic terrain are used in order to distinguish between karst and non-karst areas to observe the variation from the deterministic sample. In contrast, if the range is less, that means the average distance between two points that are similar in height is less and therefore there is more variation in the area. The average range for karst areas is 435, while the average range for non-karst areas is 690 meters. The difference between the major range and minor range, which indicates the degree of anisotropy, is higher for the karst area and this is an indicator of more variations in spatial structure and auto correlation of the karst elevation. Figure 27 shows the geohazard risk map developed for the study area.

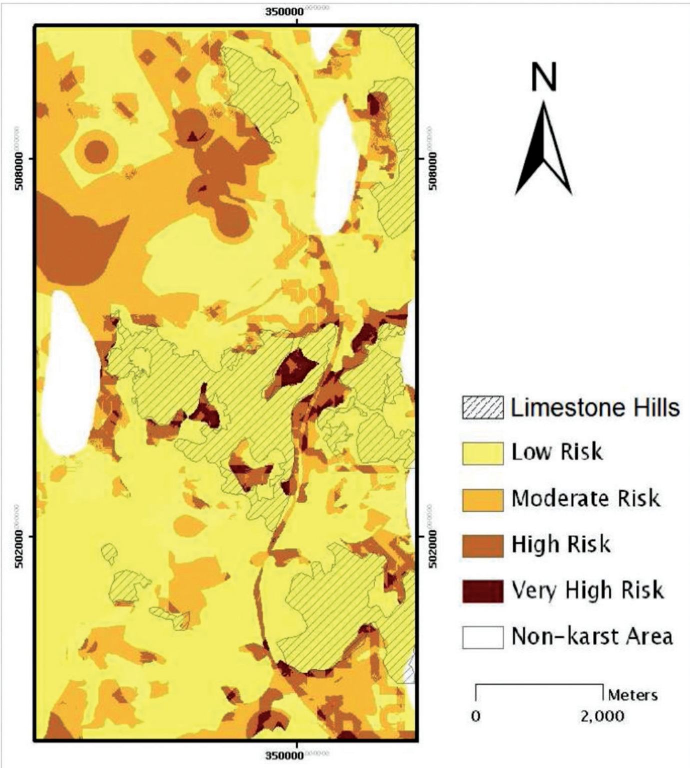

Figure 27 Geo-risk map of study area.

Earthquakes

Earthquakes are particularly difficult to predict. Tectonic activity is the main cause of destructive earthquakes, followed by earthquakes associated with volcanic activity. Where the history of earthquakes due to seismic activity is available for an area, the faults associated with the activity can frequently be identified on satellite imagery.

This section describes the work done related to earthquake prediction (Aman et al., 2010). The study involved interpreting the historical record of earthquakes and body wave (mb) in the Zagros

Mountains(ZM) (1909 –2007). The study area lies approximately between 27^{o}N to 36^{o}N in latitude and between 45^{o}E to 57^{o}E in longitude. The main trend of the ZM in West of the Iranian plateau is NW-WS, 300 km wide and extends for about 1500 km from eastern Turkey to the Straits of Hormoz.

The study shows that seismo-neotectonic activities in the west of Iran are not only irregular variations but also temporal regular changes. Frequency of earthquake, mb, geology and rocks play an important role in interpreting seismo-neotectonic activities in the Zagros Mountains in Iran. The results can be used to infer and understand the seismo-neotectonic activities and be used to predict earthquake occurence.

Earthquake frequency and distribution of monthly and annual occurrence of earthquakes for the period of 1909 to 2007, was compiled. Trend and intercept coefficients of the quantitative variables such as earthquakes were determined and analyzed by square least method. Both frequencies of the earthquakes, yearly and monthly, and their diagrams were analyzed and illustrated in GIS environment. The geostatistical data illustrate changes in seismo-neotectonic activities in the region. These changes have been fundamentally caused by plate tectonics movement.

The following relationship can be established to indicate earthquake growth rate for the Zagros Mountains;

$$\text{Ln (Frequency of Earthquake)} = \text{C (intercept)} + \text{T (Trend)} + € \quad (9)$$

where (€) is the residual effect.

Oil Spill Detection, Monitoring and Contingency Planning

Oil spills can destroy marine life as well as damage ecologically valuable species and habitats. The Malaysian coastal and marine environment is enriched by a wealth of economically and ecologically valuable species and habitats that are severely threatened by increasing oil spill incidences from passing vessels especially along the Straits of Malacca. The majority of marine oil spills result from ships emptying their billage tanks before or after entering the port. Large area oil spills result from tanker ruptures or collisions with reefs, rocky shoals or other ships. These spills are usually spectacular in the extent of their environmental damage and generate wide spread media coverage. Remote sensing, GIS and GPS tools are used for oil spill detection, monitoring and contingency planning (Assilzadeh et al., 2003).

The key operational data requirements are fast turnaround time and frequent imaging of the site to monitor the dynamics of the spill. For spill identification, high resolution sensors are generally required, although wide area coverage is very important for initial monitoring and detection. Although airborne sensors have the advantage of frequent site specific coverage on demand, they can be costly. Further, spills often occur in inclement weather, which can hinder airborne surveillance.

SAR sensors can image oil spills through the localized suppression of Bragg scale waves. Oil spills are visible on a radar image with a darker tone than the surrounding ocean. The detection of an oil spill is strongly dependent upon the wind speed. At wind speeds greater than 10 m/s, the slick will be broken up and dispersed, making it difficult to detect. Another factor that can play a role in the successful detection of an oil spill is the difficulty in distinguishing between a natural surfactant and an oil spill. Multi-temporal data and ancillary information can help to discriminate between these two phenomena.

To facilitate containment and cleanup efforts, a number of parameters can be derived from the remotely sensed imageries:

1. Spill location
2. Size and extent of the spill
3. Direction and magnitude of oil movement
4. Wind, current and wave information for predicting future oil movement
5. Coastal sensitivity index

For ocean spills, remote sensing data can provide information on the rate and direction of oil movement through multi-temporal imaging, and input to drift prediction modelling and may facilitate in targeting clean-up and control efforts. Remote sensing devices used include the airborne visible and infrared photography, thermal infrared imaging, airborne laser fluouro sensors, airborne and spaceborne optical sensors, as well as airborne and spaceborne SAR. SAR sensors have an advantage over optical sensors in that they can provide data even under poor weather conditions and when it is dark.

Case Study

On 16 October 1997 at 2100 hours a collision occurred between two oil carriers in the Straits Of Singapore and caused the worst oil spill in Singapore’s history. The vessels involved in the collision were MT Evoikos and MT 0rpin Global. An estimated 25,000 metric tons of marine fuel oil spewed into the sea from MT Evoikos as a result of the damage from the collision. The oil spill spread into the surrounding waters and islands. Within four days of the collision the oil slick reached Pulau Hantu, Pulau Senang, Pulau Pawai, Pulau

Sudong and seemed to be moving into the Straits of Malacca. The oil was also moving slowly towards Tanjung Piai under the influence of the current. A large patch of oil was found 4 n.m off Pulau Pisang and 4 n.m off Tanjung Piai. The oil slick moved north westerly into the Straits of Malacca forming an elongated shape due to the strong current flow through the narrow gap between Tanjung Piai and Pulau Karimun Besar. The oil was in the form of a thick slick with minimum effect of wind.

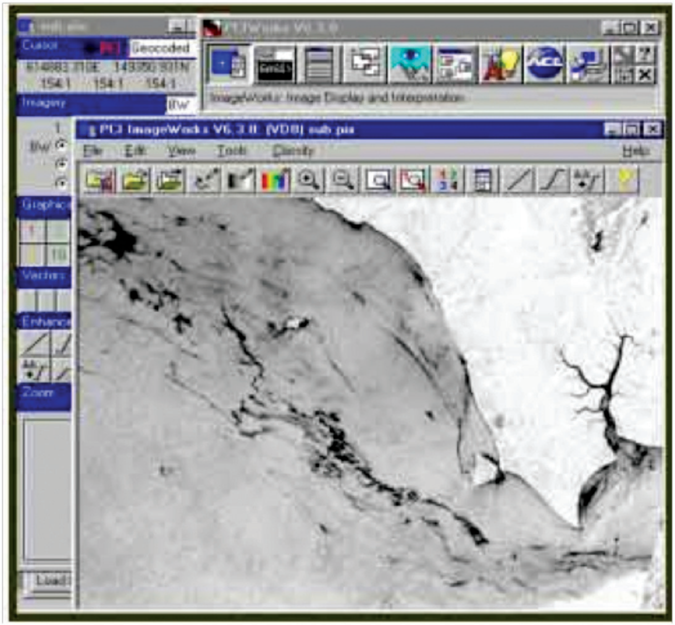

Figure 28 Radarsat image

In this Radarsat image (Figure 28) taken a week after the spill, the extent of the oil spill is visible. The dark areas off the coast represent the areas where oil is present. Oil, which floats on the top of water, suppresses the ocean’s capillary waves, creating a surface smoother than the surrounding water. This smoother surface appears dark in the radar image. As the oil starts to emulsify and clean-up efforts begin to take effect, the capillary waves are not as effectively damped and the oil appears lighter. Size, location and dispersal of the oil spill can be determined using this type of imagery.

Classified radar imagery can be used to estimate the statistical information of oil spills such as volume, length, distribution and thickness (Figure 29). The ESI map (Figure 30) serves as a quick reference for oil and chemical spill responders and coastal zone managers. The ESI map contains three types of information. (i) Shorelines which are color-coded to indicate their sensitivity to oiling; (ii) Sensitive biological resources, such as seabird colonies and marine mammal hauling grounds which are depicted by special symbols on the maps; and (iii) important human-use resources, such as water intakes, marinas and swimming beaches.

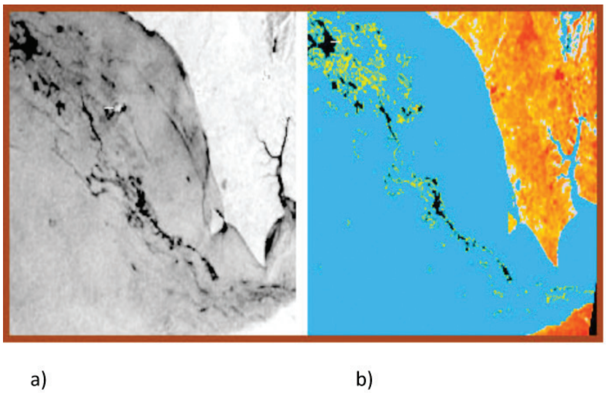

Figure 29a SAR image processing for oil spill detection in the Straits of Malacca (a) processed data after gamma filter distribution analysis on the image (b) classified image

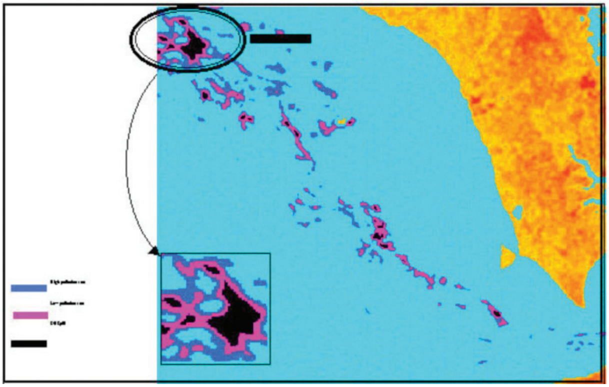

Figure 29b Oil spil classification: black colour is spill area, red is high pollution area and blue is low pollution area

Oil Spill Trajectory Simulation

In any oil spill emergency response the short-range trajectory modeling studies are the most important; and therefore it should be done in real time to give day- to -day support to oil spill contingency plans for a specific spill. On entering water, oil undergoes a complicated multi-process phenomenon. The sum of all of these processes is called weathering. Weathering includes, in the order of approximate occurrence, spreading, evaporation, dissolution and emulsification, auto-oxidation, microbiological degradation, sinking and resurfacing. While these processes are occurring, the oil slick continues to drift, under the influence of winds and ocean currents. The most important and well known among the weathering processes is the spreading and drifting, which occur simultaneously.

Based on historical oil spill records, hypothetical spill trajectories could be simulated based on ground data and meteorological information for each of the potential launch areas in the sea environment. The results could then be presented and assessed in each of the four seasons of the year from each launched area as the simulation part in a contingency plan.

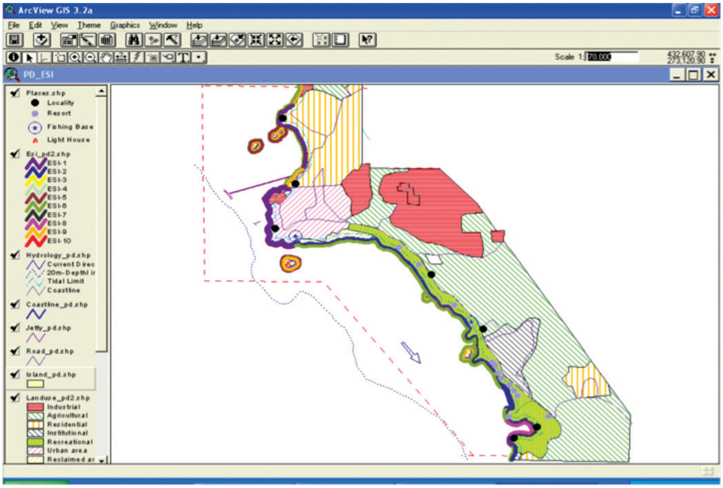

Figure 30 ESI map

Oil Spill Contingency Planning

A successful combating operation in relation to a marine oil spill is dependent on rapid response from the time the oil spill is reported till it has been fully cleared. In order to optimize the decision support capability of the surveillance system, a GIS database should be integrated with the detection tool. Information on the exact position and size of the oil spill can be plotted or visualized in a GIS environment and priority combat efforts and means, according to the identified coastal sensitive areas, can be carried out. The system can also offer opportunities for integration of oil drift forecast models (prediction of wind and current influence on the oil spill) for risk assessment. An effective response to a marine oil spill requires knowledge of the sensitivity of the coastal zones to enable determination of the priorities of combat activities, to protect the most sensitive areas. Primary data should be available for the study area such as historical data of oil spill incidents. This includes information on the incident date, location and sources of oil spill, types of spillage, width of oil spill and the effect of the spillage on the coastal environment. Apart from the base map, other data includes shoreline natural resources, coastal land use, response team information, oil spill response capability and equipment, port location and meteorological data. Raster and vectorised spill data, environmental sensitive areas and the aforementioned information will then be used for trajectory modelling and risk assessment and contingency planning.

Decision Support System for Coastal Prioritization

Prioritization is one of the powerful approaches in coastal area management planning and strategies, in relation to oil spill management (Pourvakhshouri and Mansor 2003). A 180 km shoreline of two states in west Malaysia, Negeri Sembilan and Melaka, was chosen to examine the prioritization through decision support system. Priority criteria had been selected based on local experts' knowledge in relevant domains. Coastal data acquisition was based on Malaysian ESI maps which had been validated by remote sensing data as well as field checks and Coastal prioritization ranking had been done according to coastal sensitivities. The Main required criteria for classification of the coastal sensitivities against oil pollution were defined according to the experts' knowledge. The local data was updated by area visits and field validation, and key points were located on the image and map from GPS readings. These points and features were transferred to remotely sensed images and GIS-based maps as well as linked to related information and databases, obtained from the Department of Environment and the Fisheries department, to establish an updated ESI map. The information extracted from image was transferred to GIS to obtain the vector maps for more analyses. Then the rules for running the DSS of oil spill management were prepared based on the local and non-local experts' knowledge. If-based rules of Visual Basic programming assisted in developing a user friendly engine and interface.

The main goal achieved was with regards to the establishment of a "priority ranking scale" for the coastal area, assisting the decision making procedure for management of coastal threats. According to this ranking, any risk area will be categorized into different, important areas; whether the area faced direct impact on human activities and life or not. The factors for direct impact were defined and were discussed with various people, including officers and responders. In the case of direct impact on human activity, the coastal area will be prioritized as high priority for protection and management. If the area is not under the direct impact potential group, it will go through the coding process to determine its level in the priority ranking scale.

Although all the coastal areas received a code and number for ranking, they were finally categorized into five main categories from extremely critical to low priority. It was made simple and understandable by all users through description of the category and reference to the management alternatives, which come up through the DSS management recommendations (Pourvakhshouri et al., 2004).

Natural Resources Management

Biodiversity Richness Index

Malaysia is recognized as one of 12 mega biodiversity countries in the world. In this research project, Matchinchang, Langkawi was selected as the study area due to its excellent geo-diversity, which has shaped its landscape related bio-diversity over decades (Mansor 2008). The overriding objective was to develop a spatial model for generalized plant bio-richness characterization, which would be useful for bio-conservation planning. Researchers under the project have developed remote sensing based techniques to map bio-indicators (forest and non forest, forest communities, bio-disturbance, species diversity and terrain complexity). Spatial processing tools like the Maximum Likelihood Supervised Classifier, Spatial filtering, Patchiness index, Shannon-Weaver Index, and Digital Elevation Model were used to generate the forest communities, bio-disturbance, plant species diversity and terrain complexity layers respectively. Field samplings were also conducted to collect ground information on plant species numbers using Differential Global Positioning System (GPS). The researchers also adopted the Analytical Hierarchical Process (AHP) to develop an appropriate model to map the bio-richness of the study area. Geographic Information System (GIS) was used to generate the plant bio-richness map through spatial modeling. The methodology developed in this research shows promise despite its generalized nature and can be exploited for rapid plant bio-richness assessment in other forested parts of Malaysia (Yanti et al., 2010).

The model for bio-richness is given as:

$$BR = 0.539\ SD + 0.297\ BD + 0.164\ TC \qquad (10)$$

where BR is the bio-richness index, SD is species diversity, BD is bio disturbance and TC is terrain complexity. The sub-criteria scores for SD, BD and TC are tabulated in Yanti et al. (2010).

Potential Fishing Zone

The Outline Prospective Plan (OPP3) unveiled by the government has targeted that the agricultural sector (including the fishery) will be the third engine of growth, with emphasis on the fisheries industry, particularly deep sea fishing and aquaculture to be further developed on a commercial and integrated basis, adequately supported by modern fishing infrastructure, processing, marketing, network, comprehensive human-resource development and R&D programs. The development plans focus on resource utilization on a sustainable basis.

Set in the era of ever-decreasing resources and increasing demand, modern fishing methods require that development of offshore fishing fleets be complemented by accurate forecasting of fishery stocks. The efforts presently spent on fish finding can now be more effectively directed towards the process of fish capture and preservation at sea. Setting of fish aggregating devices could also be done in areas of known fish stock congregations thereby providing greater chance for large catches for the fleet. Fishery managers can also use this information for fish planning actions to protect depleted fish stocks.

In order to catch fish efficiently, understanding fish behaviour represents the earliest attempts at fish forecasting. Since the 1900's studies on fishery and fish stocks has developed in relation to development of capture fishery. Studies on the migration of fish and its relationship with oceanographic conditions, modeling of fish populations, determination of fish stocks and the total allowable catch (TAC) further underline man's quest to understand fish behaviour so that management of the fishery industry can be achieved based on firm scientific basis and sustainable development can be achieved for future generations (Tan et al., 2002).

Satellite Fish Forecasting

The use of satellite remote sensing to provide synoptic measurements of the ocean is becoming increasingly important in fisheries research and fishing operations. Variations in ocean conditions play a key role in natural fluctuations of fish stocks and in their vulnerability to harvesting. Information on the changing ocean is necessary to understand and to eventually predict the effects of the ocean environment on fish populations. The evolving capabilities of satellite sensors and data processing technologies, combined with conventional data collection techniques, provide a powerful tool towards the development of fish forecasting and management techniques.

Since the launch of the TIROS/NOAA meteorological satellites in the 1970s, synoptic measurements of the sea surface temperature through AVHRR sensor have been routinely studied in the US. The launch of the SEASAT in 1978 brought the first satellite specifically designed for and dedicated to ocean surveillance through the Coastal Zone colour scanner (CZCS). Today the range and variety of satellites built to exacting requirements, developed to survey the colour, temperature, surface height and roughness parameters of the sea, are operated by many nations, including Japan for MODIS/ADEOS, Taiwan for the OCTS and IRS for India. Generally the equipment used has become progressively more sophisticated, enabling greater spectral and spatial resolution. This in turn has led to greater utility of remote sensing as a viable data-gathering medium (Meaden and Thang, 1996). Development of a fisheries information and advisory system for Japan has now made it routine for fishing vessels to receive advise on ocean colour and sea surface temperature for most registered fishing vessels on demand.

The development of fish forecasting models for temperate and high latitude fishery however could not be directly applied to our tropical regions. This is due to differences in fish species, and thus their behaviour, and environmental conditions of the different oceans.

A major project involving several objectives and phases to meet the goal of developing a satellite-based fishery forecasting system in the South China Sea is aimed at supporting the national aspirations of developing an efficient offshore fishery sector. More importantly, it is aimed at providing the basis for alternate ways to meet the goals of sustainable harvest of fishery resources. The project is now completed, with most of the major objectives met. Project deliverables include an efficient algorithm for the extraction of sea surface temperature (SST), sea surface salinity (SSS) and sea surface chlorophyll (SSC) for tropical regions (Salih et al., 2010, Mansor et al., 2000). A model for determination of potential fishing zones(PFZ) has also been developed (Salih et al., 2010). The model is as follows:

$$\mathbf{PFZ = \alpha 0 - \alpha 1\ (SST) + \alpha 2\ (Depth) + \alpha 3\ (SSC) + \alpha 4\ (SSS) + e} \qquad (11)$$

where,

α0, α1, α2, α3 and α4 are the coeifficients, and
ε is the residual

Although this model has been field tested with good results, its application in real time mode will depend on availability of real time satellite data for SST, SSS, and SSC, and the development of a web based fishery information system to disseminate PFZ and other oceanographic information to registered users.

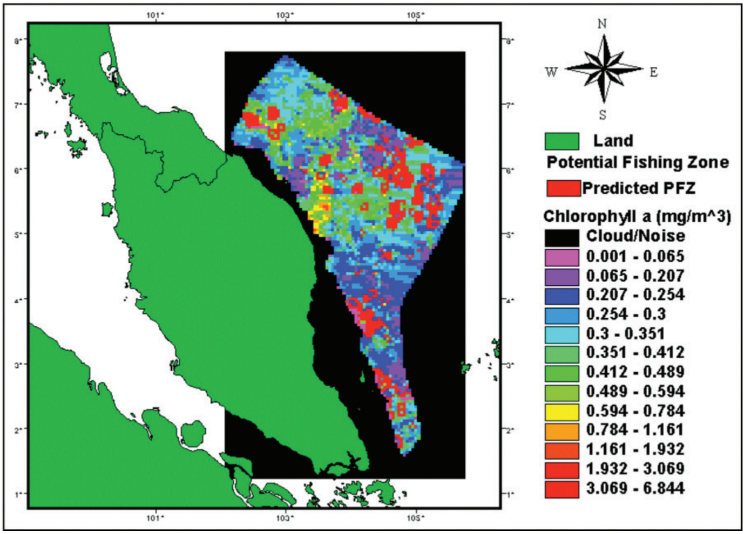

Figure 31 Potential fishing zone map for 21 to 27 September 2000 (MODIS)

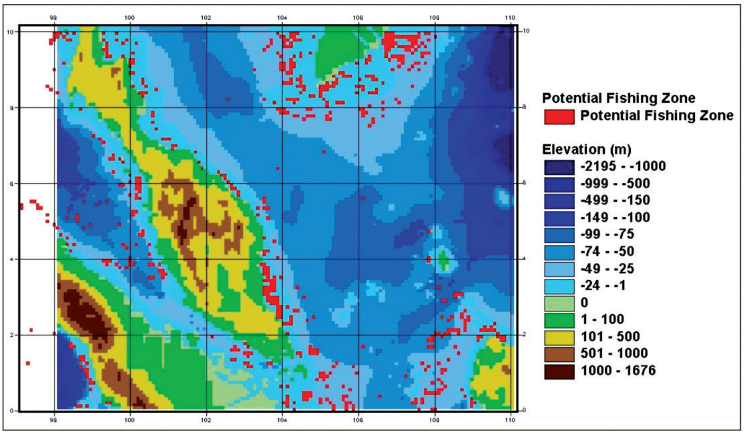

Figure 32 Potential fishing zone map in relation to bathymetric depth

Oil Palm Plantation Management

There is a high demand for rapid and accurate oil palm tree counting not only for more efficient oil palm plantation management but also for reliable valuation of oil palm estates for the real estate, banking and insurance industries. Currently tree counting is done manually by estate labourers or via visual digitization of the palm trees from satellite imagery, by professionals. These techniques are time consuming and are subject to human error. We have developed remote sensing based spatial tools for automatic oil palm tree counting for 5 palm age groups, which were 2, 5, 10, 15 and 18 year old palms (Wan Zanariah et al., 2010). The acquired QUICKBIRD imagery was first treated with a specially designed 15 x 15 smooth filter to delineate the dome shaped palm tree crowns, subsequently a 7 x 7 edge enhancement filter was used to delineate the inner high intensity diameter of the palm crowns and finally the individual palm centroids were marked out using an image threshold technique.. It was observed that the centroids of the palms were well separated for all age groups except for the 2 year old palms, attributed to mixed reflections from both the palm fronds and the leguminous cover crops. The centriods were then vectorized for automatic counting in a GIS`. The accuracies obtained for the 2, 5, 10, 15 and 18 age groups were 96.4, 99.1, 98.8, 98.7 and 98.1% respectively. In the GIS, these centroids were essentially point files of individual trees, where attributes such as age, plant condition, yield and production cost were incorporated, thus establishing a palm tree inventorying system. This system is useful for plantation managers, most importantly for evaluating crop performance, evaluating reliability of planting materials and evaluating the plantation’s market value.

THE FUTURE OF IMAGERY

Sensing the Earth has proven to be a tremendously valuable tool for understanding the world around us. Over the last half-century, we have built a sophisticated network of satellites, aircraft, and ground-based remote sensing systems to provide raw information from which to understand past, current and future changes on the Earth. Through remote sensing, knowledge of the Earth and how it functions has expanded rapidly in the last few decades. Applications of this knowledge, from natural hazard prediction to resource management, have already proven their benefit to society many times over. As demand for such information grows exponentially; what will remote sensing be like a decade from now and what new capabilities will there be?

Mass-market consumer applications are emerging that will radically transform our use of Earth information over the next decade. Advanced sensor technologies will allow us to view the Earth in three dimensions at nested spatial scales. Further, vast networks of sensors will bring the most remote corner of the world into our daily lives and Internet geospatial portals and geographic search engines will put all of this information at our fingertips. GPS-based devices which are now widely employed for car navigation, Internet maps and virtual worlds (such as Google Earth and Microsoft Virtual Earth) enable everything from education to vacation planning to real-estate hunting while mobile phones provide a ubiquitous distribution platform for location-based information. The substantial thrust is in doing things faster, cheaper and better. Spatial and temporal sampling in the non-visible portions of the spectrum (particularly infrared and microwave) will improve with time. Further, with the growing demand, novel sensor approaches are also likely to appear. One such possibility is in “interactive remote sensing,” where farmers genetically “tag” crops to enhance the remotely detectable spectral signature for crop monitoring.

An area which will receive much attention is imagery constellation where data providers are able to weigh various collection assets, either satellite, aerial photgraphy or UAV, to deliver the requirements of customers. With more than one high-resolution satellite available, customers are guaranteed not only more coverage of the planet, but more frequency and accuracy. The combination of more satellite revisits with aerial imagery also enables a time-sequenced, precision image that is down to six centimeters. In a nutshell, a constellation of imagery assets provides the currency, resolution, and accuracy that facilitates response to any developing situation. Coupled with historical archived data and aerial assets, a constellation can easily show the changes that have occurred over time and monitor areas of interest that are specific to a given customer. In the future customers will be able to subscribe to their areas of interest, search archives for existing data, order and collect data based on collection frequencies of their choice.

Community Remote Sensing is an emerging field that combines remote sensing with citizen science, social networks and crowd-sourcing to enhance the data obtained from traditional sources to enable better stewardship of our planet. It includes the collection, calibration, analysis, communication, or application of remotely sensed information by these communities. Indeed, data supported and provided by people and sensors "on the ground" will provide much fuller insight for projects around the world, such as disaster management and emergency response.

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BIOGRAPHY

Shattri Mansor was born in Kampung Raja, Padang Matsirat, Langkawi, Kedah in 1960. He obtained his early education at Kelibang Primary School and Mahsuri Secondary School. He then completed his secondary school education at Sultan Abdul Hamid College, Alor Setar. He studied surveying at Universiti Teknologi Malaysia where he obtained his B.Sc. degree in 1984. He then joined Universiti Pertanian Malaysia (UPM) as a Tutor at the Department of Civil and Environmental Engineering. Then he proceeded with his Master Degree in Engineering Surveying & Geodesy at the Department of Civil Engineering, University of Nottingham, United Kingdom. He was employed as a lecturer at the Department of Civil Engineering in 1986. Subsequently, he did his PhD in the Department of Applied Physics, Electronic and Manufacturing Engineering, University of Dundee, on "Quantitative analyses of thermal infrared satellite data for geophysical investigations". Dr. Shattri was promoted to Professor in 2005. He is currently the Director of Development at Universiti Putra Malaysia.

Dr. Shattri has taught a total of 10 subjects at Postgraduate, Bachelor and Diploma levels. He has been contributing continuously to the development of various engineering programmes, curricula and syllabi during his 25 years of service as tutor, lecturer, associate professor and professor at the Faculty of Engineering. His most recent and valuable contribution is as the key person developing the Master of Science programme in the area of Remote Sensing and GIS. He was the pioneer and coordinator or the MS (Remote Sensing and GIS) programme that now has an enrollment of over 70 students from ten countries. Being a proactive researcher, he was entrusted with the task of setting up the Spatial and Numerical Modeling Laboratory in 1999, under the Institute of Advanced Technology, UPM.

Dr. Shattri has been the leader in acquiring and completing several major research projects with a total funding of RM 3.0 million from the Ministry of Science, Technology and Innovation (MOSTI). Dr. Shattri maintains diverse research interests including image processing, remote sensing and GIS. His major research effort includes feature extraction from satellite imagery, spatial decision support system, fish forecasting, oil spill detection and monitoring system, UAV-based remote imaging, disaster management and early warning systems. As a result, hundreds of his works have been recognized and published extensively in renowned journals and conference proceedings. He has also been an invited speaker and panelist at various conferences. In tandem with his expertise, Dr. Shattri has also supervised and co-supervised a total of *22 MS students, 24 PhD students and 6 post doctorates*. He is also an external examiner for students from other higher learning institutions, for their MS/PhD degree.

Dr. Shattri holds membership to various organizations and institutions. He is currently the Co-Chairman for the International Society of Photogrammetry & Remote Sensing (ISPRS) Working Group II/7, an *executive committee member* for the Institution of Surveyors Malaysia (ISM Geomatics and Land Surveying Division), a member of the *National Committee* on Mapping and Spatial Data, a *technical advisor* for the development and implementation of the Malaysian Geospatial Data Infrastructure, a member of SPIE and a member of the National Working Group on Route Information, Guide Signs and Addresses. He has served as a *councilor* for the Institution of Surveyors Malaysia (ISM), as an *Editor* for the Malaysian Surveyor Journal and as an executive committee member for the Malaysian Remote Sensing Society. He is currently an Editorial Board member of the Malaysian Journal of Remote

Sensing and GIS, Disaster Advances Journal and International Journal of Geoinformatics.

In University Putra Malaysia, Dr. Shattri had served on more than 40 committees, was also a key committee member and conference chairman of more than 10 major conferences, and also held various administrative posts. He is currently the chairman of the Asset Management Committee and the Infrastructure and Traffic Committee.

In summary, Dr. Shattri is a well-rounded person. As an academician he is very effective and excellent in his teaching. He also participates actively in research. As a leader he manages and leads his group and organization towards commendable achievements. He has received several awards at the international and national levels, including 2 Gold Medals at the Malaysian Technology Expo (2006), Gold Medal at ITEX Geneva (2005), Gold Medal at IPTA Exhibition (2005), Bronze Medal at EUREKA (2005), *Best Article Award (2000),* Silver Medal at the National Expo of Science & Technology (2001 & 2003) and several awards at UPM level, including the UPM Excellence Research Award (2003 & 2005) and UPM Excellent Service Award (1996 & 2001).

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1. Development Of An Integrated Biodiversity Support System At Landscape Level
2. Development Of An Early Warning System For Monitoring Water Catchments
3. Application of RS & GIS Technique in Fish Forecasting
4. Low Cost Real Time System for Detecting Hydro Carbon
5. Airborne Interferometric and Polarimetric Radar Analysis for Resource and Environmental Application
6. Expert System for Routing & Siting
7. E- Spatial Tool for Digital Earth
8. Oil Spill Contingency Planning System
9. Integrated Monitoring System for Disaster Management
10. Wave Spectra
11. Development Of A Spatial Multi-Criteria Decision Support Tool For Oil Palm Plantation Management
12. Flood Zone Mapping Using Satellite Imageries

The following projects were funded through FRGS, RUGS and UPM research grants:

1. Mobile Fish Finder

2. Development of Artificial Neural Network and Advanced Fuzzy Logic Model for Mapping, Monitoring & Mitigation of Landslides
3. Determination of Geophysical Parameters from Space

The writer also acknowledges the contributions of research colleagues at the Spatial and Numerical Modeling Laboratory (ITMA) and Faculty of Engineering and his graduate students. Materials included in this lecture are from the collection of knowledge published in their dissertations, journals, seminars, conferences and workshops.

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ABSTRACT

Sensing the Earth has proven to be a tremendously valuable tool for understanding the world around us. Over the last half-century, we have built a sophisticated network of satellites, aircraft, and ground-based remote sensing systems to provide raw information from which we derive and improve our knowledge of the Earth and its phenomena. Through remote sensing, our basic scientific knowledge of the Earth and how it functions has expanded rapidly in the last few decades. Applications of this knowledge, from natural hazard prediction to resource management, have already proven their benefit to society many times over. Today maps and satellite imageries have become an integral part of the developmental process and have also triggered new business opportunities. Maps are essential at all stages of infrastructure development, resource planning and the disaster management cycle. Satellite imagery/data can be used for everything from ground truthing and change detection, to more sophisticated analyses, including feature extraction and natural hazard prediction. As imagery has become more accessible and more affordable in recent years, there is also a growing convergence of imagery and geographic information system (GIS) applications. Geospatial scientists and analysts thus, need to be able to easily access imagery and move seamlessly between GIS and image processing applications to derive the most information possible from them. Technologically, the challenge is to design sensors that exhibit high sensitivity to the parameters of interest while minimizing instrument noise and impacts of other natural variables. The scientific challenge is to develop retrieval algorithms that describe the physical measurement process in sufficient detail, yet are simple enough to allow robust inversion of the remotely sensed signals. Considering the exponential growth of data volumes driven by the rapid progress in sensor and computer technologies in recent years,

the future of remotely sensed data should ideally be in automated data processing, development of robust and transferable algorithms and processing chains that require little or no human intervention. In meeting the above mentioned challenges, some research works have been done at Universiti Putra Malaysia. These works cover all aspects of the remote sensing process, from instrument design, image processing, image analysis to the retrieval of geophysical parameters and their application in natural resources planning and disaster management. Some of the major research efforts include feature extraction from satellite imagery; spatial decision support system for oil spill detection, monitoring and contingency planning; fish forecasting; UAV-based remote imaging and natural disaster management and early warning systems for floods and landslides. This lecture concludes that through remote sensing, our basic scientific knowledge of the Earth and how it functions have expanded rapidly in the last few decades. Applications of this knowledge, from natural hazard prediction to resource management, have already proven to be beneficial to society many times over. As the demand for even faster, better and more temporally and spatially variable information grows dramatically, this lectures answers the question of what remote sensing will be like in the coming decades and the new capabilities and challenges that will emerge.

INTRODUCTION

Satellite pictures of the earth have become commonplace as seen in daily weather reports on television, where regular images taken by geostationary satellites show the weather and various atmospheric phenomena. With online Web-based virtual globes such as Google Earth or Virtual Earth, satellite imagery can be zoomed in on from the full earth disk to detailed views of any place on the earth in a matter of seconds.

What is the first thing most users do in Google Earth? Typically they fly to their homes, navigate around their neighborhoods and perhaps explore potential travel and vacation spots. While this is a wonderful introduction to the power, utility and even pleasure of using Google Earth, increasingly there are much more interesting applications being launched that leverage the power of Google Earth to help the people, animals and plants of our planet.

Google Earth has placed the reality of terrestrial geography within the reach of every individual. Today maps and satellite imagery have become an integral part of the developmental process and have also triggered new business opportunities. The term 'geospatial' is the hot word around the Internet as Internet search companies have come to recognize that information relevant to our everyday lives should be naturally organized and effectively located in a geospatial context. This new geospatial world is revolutionary for both consumers and businesses. People working in the geospatial field will play a central role in this transformation as personal and professional lives are altered by this new technology.

Satellite imagery can be used for everything from ground truthing and change detection, to more sophisticated analyses, including feature extraction and land-use classification. As imagery has become more accessible and more affordable in recent years, there is also a growing convergence of imagery and geographic information systems (GIS) applications. Geospatial scientists and analysts are thus able to easily access imagery and move seamlessly between GIS and image processing applications to derive the most information possible from them.

Data from satellites have exposed great potential in environmental monitoring and resource management capabilities thus increasing the curiosity of researchers and the need to answer questions such as:

- The growth rates of urban areas and how infrastructure development match up with the increasing localized demand for transportation, energy, water and food
- Accurate retrieval of rainfall rates from satellite observations for flood prediction, landslides, mosquito-borne epidemics and other natural hazards
- Deforestation and how it affects biodiversity loss and the global carbon balance
- The rate of change of fresh water resources and wetlands and how to mitigate climate change impacts
- Rise in sea surface temperatures and its effect on global warming
- Measurements of subtle changes in sea surface salinity and its effects on ocean circulation
- Is subsidence threatening buildings in urban areas that had previously been mined?

These and many more questions can only be answered by combining remote sensing and geophysical modeling capabilities in a process-oriented framework. This has become more important than ever since climate change, continued population growth and shrinking natural resources have all become truly global problems requiring, as part of the solution, global monitoring capabilities to better understand how to act locally.

Technologically, the challenge is to design sensors that exhibit high sensitivity to the parameters of interest while minimizing instrument noise and impacts of other natural variables. The scientific challenge is to develop retrieval algorithms that describe the physical measurement process in sufficient detail and yet are simple enough to allow a robust inversion of the remotely sensed signals. Considering the exponential growth of data volumes driven by the rapid progress in sensor and computer technologies in recent years, the future of the remotely sensed data should ideally be in automated data processing, in the development of robust and transferable algorithms and processing chains that require little or no human intervention.

This lecture is designed to cover all aspects of the remote sensing process, from instrument design, image processing, image analysis to the retrieval of geophysical parameters and their application in infrastructure development, natural resources planning and disaster management.

WHY IMAGERY?

The use of remotely sensed data can improve decision making by way of a variety of physical and environmental parameters and information that can be retrieved from them. Some of the benefits of imagery data from satellite remote sensing are the:

- continuous acquisition of data
- up-to-date information (regular revisits to area of study)
- wide coverage and good spectral resolution
- accurate data for information and analysis
- archive of historical data

Overview of Remote Sensing Attributes

Remote sensing is a broad term, encompassing a wide range of sensors that acquire data about the Earth and its environment, and other physical objects and processes. It is a highly interdisciplinary field requiring the combined efforts of electrical engineers, physicists, mathematicians, computer scientists, surveyors, photogrammetry, GIS and the various geoscientists. Some important characteristics of remote sensing are that:

- Sensors operate in different regions of the electromagnetic spectrum (visible, infrared, and microwave regions) and may be mounted on spaceborne, airborne and terrestrial platforms to acquire geophysical data from global to local scales.
- An important, and often the most difficult problem, is to find the correct relation between the remote measurements and the target parameters
- Due to the confounding influence of other natural parameters it may be possible to achieve ambiguous interpretation of the remotely sensed data. The limited number of independent measurements may also mean that an exact solution is unattainable or at the least, impracticable.

These characteristics give rise to some technological and scientific challenges in remote sensing.

So, what exactly is remote sensing? Remote sensing in the simplest form is measuring or acquiring information of an object, place or phenomena without being in direct contact with it. According to the on-line Wikipedia, remote sensing is the small or large-scale acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing device(s) that are wireless, or not in physical or intimate contact with the object (such as by way of aircraft, spacecraft, satellite, UAV, buoy or ship). The basic concept behind optical remote sensing is illustrated in Figure 1.

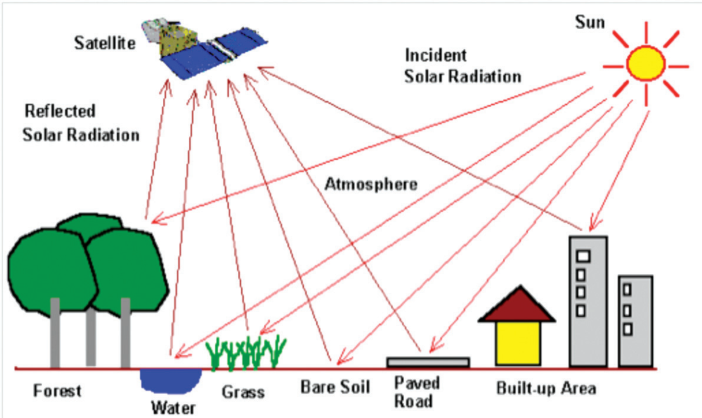


Figure 1 Basic Concept of Remote Sensing

There are two basic types of sensors: passive and active sensors. Passive sensors record radiation reflected from the earth's surface. The source of this radiation must come from *outside* the sensor. In most cases this is solar energy. Due to this energy requirement, passive solar sensors can only capture data during daylight hours. The MAC sensor system on the RazakSat satellite is a passive sensor.

Active sensors are different from passive sensors. Unlike passive sensors, active sensors require the energy source to come from *within* the sensor. 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..

How Sensors Work

Sensors collect and store data about the spectral reflectance of natural features and objects, both of which reflect radiation. This radiation can be quantified on an electromagnetic spectrum.

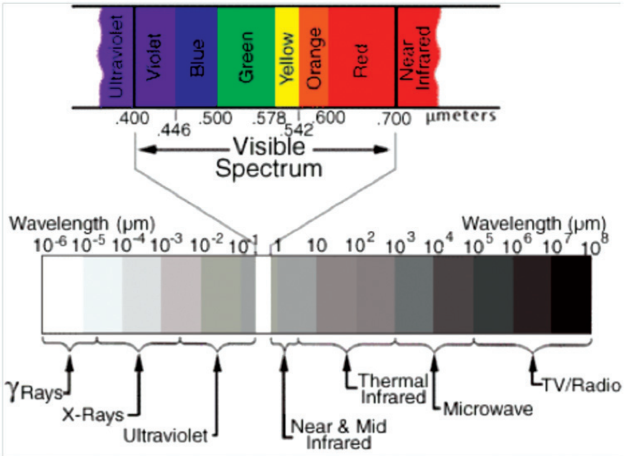


Figure 2 *Electromagnetic Spectrum*

The electromagnetic spectrum is a continuum of electromagnetic energy arranged according to its frequency and wavelength (Figure 2). As the electromagnetic waves are radiated through space, their energy interacts with matter and one of three reactions takes place. The radiation will either be:

1. reflected off the object;
2. absorbed by the object; or
3. transmitted through the object.

The total amount of radiation that strikes an object is referred to as the incident radiation, and is equal to:

incident radiation = reflected radiation + absorbed radiation + transmitted radiation

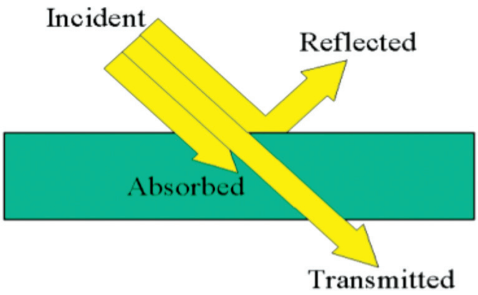


Figure 3 Example of Reflected, Absorbed and Transmitted Radiation

Of these three types of radiation, remote sensing is primarily concerned with reflected radiation. This is the same radiation that causes our eyes to see colors, causes infrared film to record vegetation, and allows radar images of the earth to be created.

Spectral reflectance is the portion of incident radiation that is reflected by a non-transparent surface. The fraction of energy reflected at a particular wavelength varies for different features. Additionally, the reflectance of features varies at different wavelengths. Thus, two features that are indistinguishable in one spectral range may be very different in another portion of the spectrum. This is an essential property of matter that allows for different features to be identified and separated by their spectral signatures.

Imaging Characteristics of Remote Sensing Systems

The success of remote sensing data acquisition requires an understanding of the basic characteristics of remote sensing systems. There are four major resolution characteristics determining the type of geospatial data that can be detected by remote sensing systems. In general, resolution is defined as the ability of an entire remote-sensing system, including lens antennae, display, exposure, processing and other factors, to render a sharply defined image. Resolution of a remote-sensing system comprises of different forms:

i. Spatial Resolution: in terms of the geometric properties of the imaging system, is usually described as the instantaneous field of view (IFOV). The IFOV is defined as the maximum angle of view in which a sensor can effectively detect electro-magnetic energy (Figure 4).

ii. Spectral Resolution: of a remote sensing instrument (sensor) is determined by the band-widths of the Electro-magnetic radiation of the channels used. High spectral resolution, thus, is achieved by narrow bandwidth widths which collectively, are more likely to provide a more accurate spectral signature for discrete objects than broad bandwidth (Figure 5).

iii. Radiometric Resolution: is determined by the number of discrete levels into which signals may be divided.

iv. Temporal Resolution: is related to the repetitive coverage of the ground by the remote-sensing system. The temporal resolution of Landsat 5 is sixteen days.

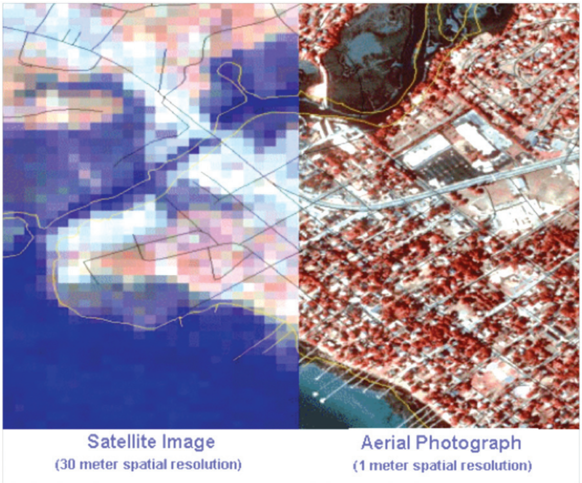


Figure 4 The scale of a project usually determines what type of imagery should be used

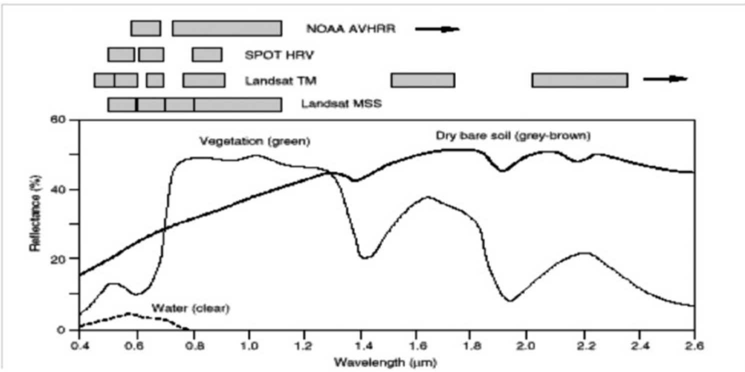


Figure 5 Typical spectral reflectance curves of common earth surface materials in the visible and near-to- mid infrared range. The positions of spectral bands for some remote

Data Acquisition

In this section, we will take a closer look at the characteristics of remote sensing platforms and sensors and the data they collect. In order for a sensor to collect and record energy reflected or emitted from a target or surface, it must reside on a stable platform, removed from the target or surface being observed. Platforms for remote sensors may be situated on the ground, on an aircraft or UAV (or some other platform within the Earth’s atmosphere), or on a spacecraft or satellite outside of the Earth’s atmosphere.

Ground-based sensors are often used to record detailed information about the surface which is compared with information collected from aircraft or satellite sensors. In some cases, this can be used to better characterize the target which is being imaged by these other sensors, making it possible to better understand the information in the imagery.

Sensors may be placed on a ladder, scaffolding, tall building, crane, etc. Aerial platforms are primarily stable wing aircraft, although helicopters and UAV are occasionally used. Aircraft are often used to collect very detailed images and facilitate the collection of data over virtually any portion of the Earth’s surface at any time.

In space, remote sensing is conducted from satellites. Satellites are objects which revolve around the Earth. Satellites include those platforms launched for remote sensing, communication and telemetry (location and navigation) purposes. Due to their orbits, satellites permit repetitive coverage of the Earth’s surface on a continuing basis.

Most earth observation satellites, (such as the Landsat, SPOT and IRS series) are in a near polar, sun-synchronous orbit. At altitudes of around 700 - 900km the satellites revolve around the earth in approximately 100 minutes and on each orbit cross a particular line of latitude at the same local (solar) time. This ensures that the satellite can obtain coverage of most of the globe, replicating the coverage typically within 2 - 3 weeks. With sensors which can be pointed sidewards from the orbital path, revisit times with high-resolution frames can be reduced to just a few days. Due to evaporation, the atmosphere normally contains less moisture early in the morning, and so to get a clear picture whilst achieving sufficient solar illumination, satellites often are set to overpass the target area at around 9:30 - 10:30 a.m. local time.

Exceptions to these sun-synchronous orbits include the geostationary meteorological satellites (such as the Meteosat and GOES satellites). These have a 36,000km orbit and rotate around the earth every 24 hours remaining above the same point on the equator, acquiring frequent images showing cloud and atmospheric moisture movements for almost a full hemisphere. Further, satellites required to obtain very high resolution (<2m) images, which often orbit at altitudes of around 200-300 km, are currently not able to operate in a sun-synchronous orbit.

Optical scanning techniques take one of two main forms. A ‘switch-broom’ sensor consists of an oscillating mirror, which directs the reflected light to a few sensors, building up an image by a few lines of picture elements (pixels) at a time. However, more common in modern sensors is the ‘push-broom’ sensor, an array of several thousand CCD-sensors, each recording a single path (column), which are combined to build an image as the satellite orbits the earth.

Whichever scanning method is used, each satellite records an image of constant width but potentially several thousand kilometres in length. Once the data have been received on earth, the imagery is usually split into approximate square sections for distribution. These nominal image sizes typically range from 11x11km (IKONOS, 1m pixels) to 185km x 170km (Landsat-7, 15m and 30m pixels).

The previous sections provide a representative overview of specific systems available for remote sensing in the (predominantly) optical portions of the electromagnetic spectrum. There are however, many other types of less common sensors which are used for remote sensing purposes. We will briefly touch on a few of these other types of sensors. The information is not comprehensive but serves as an introduction to alternative imagery sources and imaging concepts.

Video

Although coarser in spatial resolution than traditional photography or digital imaging, video cameras provide a useful means of acquiring timely and inexpensive data and vocally annotated imagery. Cameras used for video recording measure radiation in the visible, near infrared and sometimes mid-infrared portions of the EM spectrum. The image data are recorded onto cassette and can be viewed immediately.

FLIR

Forward Looking InfraRed (FLIR) systems operate in a similar manner to across-track thermal imaging sensors. However, they provide an oblique rather than nadir perspective of the Earth´s surface. Typically positioned on aircraft or helicopters, and imaging the area ahead of the platform, FLIR systems provide relatively high spatial resolution imaging that can be used for military applications, search and rescue operations, law enforcement and forest fire monitoring.

Laser Fluorosensor

Some targets fluoresce, or emit energy, upon receiving incident energy. This is not a simple reflection of the incident radiation, but rather an absorption of the initial energy, excitation of the molecular components of the target materials, and emission of longer wavelength radiation which is then measured by the sensor. Laser fluorosensors illuminate the target with a specific wavelength of radiation and are capable of detecting multiple wavelengths of fluoresced radiation. This technology has been proven for ocean applications, such as chlorophyll mapping and pollutant detection, particularly for naturally occurring and accidental oil slicks.

Lidar

Lidar is an acronym for LIght Detection And Ranging, an active imaging technology very similar to RADAR (see next paragraph). Pulses of laser light are emitted from the sensor and energy reflected from a target is detected. The time required for the energy to reach the target and return to the sensor determines the distance between the two. Lidar is used effectively for measuring heights of features, such as forest canopy height relative to the ground surface, and water depth relative to the water surface (laser profilometer). Lidar is also used in atmospheric studies to examine the particle content of various layers of the Earth´s atmosphere and acquire air density readings and monitor air currents.

RADAR

RADAR stands for RAdio Detection And Ranging. RADAR systems are active sensors which provide their own source of electromagnetic energy. Active radar sensors, whether airborne or spaceborne, emit microwave radiation in a series of pulses from an antenna, looking obliquely at the surface, perpendicular to the direction of motion. When the energy reaches the target, some of the energy is reflected back towards the sensor. This back scattered microwave radiation is detected, measured and timed. The time required for the energy to travel to the target and return back to the sensor determines the distance or range to the target. By recording the range and magnitude of the energy reflected from all targets, as the system passes by, a two-dimensional image of the surface can be produced. As the RADAR has its own energy source, images can be acquired day or night. Moreover, microwave energy is able to penetrate through clouds and most rain, making it an all-weather sensor.

Synthetic aperture radar (SAR) is another imagery type that consists of information obtained by instruments emitting radio signals rather than passively sensing naturally reflected radiation. A typical radar measures the strength and round-trip time of the microwave signals that are emitted by a radar antenna and reflected off a distant surface or object. The radar antenna alternately transmits and receives pulses at particular microwave wavelengths (in the range 1 cm to 1 m, which corresponds to a frequency range of about 300 MHz to 30 GHz) and polarizations (waves polarized in a single vertical or horizontal plane). Sensors such as ERS 1 and 2 and Radarsat 1 were designed to generate synthetic aperture radar (SAR) images for various applications (Mansor 2000). The ERS data, with its high accuracy positional information, could be used to generate interferograms for high accuracy elevation data. Improvement in interfeometry has also continued with SRTM, TerraSAR-X and TanDEM-X and recently, with sensors such as Envisat

Stereoscopic Data Acquisition

Another important development has been the improved acquisition of stereoscopic data. Sensors such as ASTER, SPOT HRS and ALOS PRISM allow the collection of two or three images within seconds of each other, using fore and aft sensors, whilst agile sensors such as Worldview and GeoEye collected stereo data in a single overpass by changing the pointing direction of the single sensor. The improved high resolution sensors also have multispectral channels, providing colour images which are co-registered with the panchromatic channel. Data fusion allows these channels to be combined, so that the higher resolution and the multispectral characteristics are retained.

Other groups of sensors collect stereoscopic images for generation of digital elevation models (DEMs). Some microwave sensors use synthetic aperture radar technology, which now produce resolution of 1m, interferometrically to produce elevation data and to monitor tectonic movement and subsidence at the millimeter level. These imaging sensors are supported by Global Navigation Satellite Systems (GNSS) which are vital for providing positional information, both for mapping directly and for giving the position of other platforms. The combination of imaging system and positioning system, together with the use of inertial navigation systems, are the driving force behind LiDAR, mobile mapping systems and interferometric synthetic aperture radar systems (IfSAR).

UAV (Unmanned Aerial Vehicle)

The UAV, also called UAS (unmanned aerial system), is an inexpensive airborne instrument platform on which different data capturing sensors can be mounted (optical, Infrared, Radar, Laser, Sonar etc). It opens new possibilities in remote sensing imagery application in areas of research, resource management and environmental surveillance (Mansor 2008). UAV aerial photography is very flexible as it gives complete control over the angle, lighting, and overall appearance of the images being taken. It also has an added. This flexibility allows its use for a variety of projects, among others, aerial surveying and pictures of inaccessible and dangerous places.

Image interpretation

Feature identification and image interpretation of remote sensing imagery involves the identification and/or measurement of various targets in an image in order to extract useful information about them. Targets in remote sensing images may be any feature or object which can be observed in an image, and have the following characteristics: Targets may be a point, line or area feature. This means that they can have any form, from a bus in a parking lot or plane on a runway, to a bridge or roadway, to a large expanse of water or a field.

i. The target must be distinguishable; it must contrast with other features around it in the image.

ii. Recognizing targets is the key to interpretation and information extraction. Observing the differences between targets and their backgrounds involves comparing different targets based on any, or all, of the visual elements of tone, shape, size, pattern, texture, shadow and association.

Data Processing

Digital Image Processing is a collection of techniques for the manipulation of digital images by computers. The raw data received from the imaging sensors on the satellite platforms contain flaws and deficiencies. To overcome these flaws and deficiencies, in order to get the originality of the data, it needs to undergo several stages of processing. This will vary from image to image depending on the type of image format, initial condition of the image and the information of interest and the composition of the image scene. Satellite image processing typically involves image geo-coding, enhancement, filtering and band transformation. Over the years many image processing and analysis techniques have been developed to aid in the interpretation of remotely sensed data and to extract as much information as possible. The choice of techniques or algorithms in image processing depends on the goals of each individual project.

Pre-processing

Pre-processing involves initial processing of the raw satellite data, carried out to correct for any distortion due to the characteristics of the imaging system and imaging conditions. Currently, in most cases pre-processing is carried out by the ground station or image providers before it reaches the end-user, unless the user has certain requirements. Generally, the procedures of pre-processing include radiometric correction to correct for uneven sensor response over the whole image and geometric correction to correct for geometric distortion due to the earth's rotation and other conditions such as oblique viewing. Image may also be transformed to conform to a specific map projection system. For precise geo-referencing, ground control points (GCPs) are used to register the image for accurate geographical location of an area on the image.

Image Enhancement

Image enhancement is the improvement of visual interpretation and visual appearance of the objects in the image through techniques such as grey level stretching to improve the contrast and spatial filtering to enhance the edges. Hazy appearance of a image may be due to the scattering of sunlight by the atmosphere into the field of view of the sensor. This consequently degrades the contrast between different objects in the image.

As an image enhancement technique often drastically alters the original numeric data, it is normally used only for visual (manual) interpretation and not for further numeric analysis. Common enhancements include image reduction, image rectification, image magnification, transect extraction, contrast adjustments, band ratioing, spatial filtering, Fourier transformations, principal component analysis and texture transformation.

Figure 6 (a) shows an original image that has been linear enhanced (b). The hazy appearance as seen in the original image has generally been removed and the contrast between different features has improved.

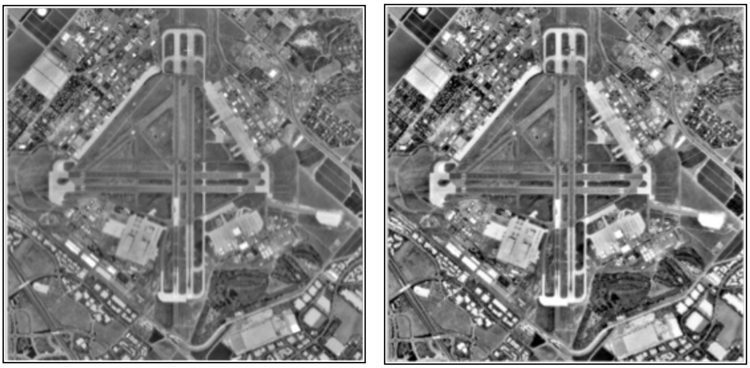


Figure 6 (a) Original image (b) Linear enhanced image

Selecting best band combinations for image display could be time consuming, especially for hyperspectral data. We have developed an algorithm for selecting the best three bands for image visualization (Teoh et al., 2003). This algorithm uses the degree of between-cluster separability in a spectral band and a correlation coefficient to compute the statistical parameter called 'Best Three Bands Combination Index' (BTBCI). The highest value of BTBCI should be the three bands having the most information content. This algorithm was compared with another statistical method called 'Optimum Index Factor' (OIF). Comparison results shown that the band combination of 1, 4 and 5 was found to be the top ranked in the BTBCI and OIF for Landsat TM data. However, the ranking results were significantly different when applied to the MODIS data; where band combination 3, 7 and 20 had top rank in the BTBCI while for OIF it was 8, 22 and 42. The display quality of these two images was different where band combination 3, 7 and 20 was shown to be smoother than the band combination 8, 22 and 42.

Image Filtering

Image filtering is a process by which an image can be enhanced or signal noise removed through modification, warp and mutilation. It is often used to eliminate unwanted frequencies from an input signal or to select a desired frequency in which to display an image. There are a wide range of filters and filter technologies, some of which include spatial filters (average, mean, mode), edge detection filters, Gaussian filter (low pass or band pass filters), high pass filters etc.

Spatial filtering is used to enhance the appearance of an image. Spatial filters are designed to highlight or suppress specific features in an image based on their spatial frequency. Spatial frequency refers to the frequency of the variations in tone that appear in an image. "Rough" textured areas of an image, where the changes in tone are abrupt over a small area, have high spatial frequencies, while "smooth" areas with little variation in tone over several pixels, have low spatial frequencies.

Image Transformation

Image transformations typically involve the manipulation of multiple bands of data, whether from a single multispectral image or from two or more images of the same area acquired at different times (i.e. multi temporal image data). It generate "new" images from two or more sources which highlight particular features or properties of interest, better than the original input images.

Basic image transformations apply simple arithmetic operations to the image data. Image subtraction is often used to identify changes that have occurred between images collected on different dates. This type of image transformation can be useful for mapping changes in urban development around cities and for identifying areas where deforestation is occurring.

Image division or spectral ratioing is one of the most common transforms applied to image data. Image ratioing serves to highlight subtle variations in the spectral responses of various surface covers. By ratioing the data from two different spectral bands, the resultant image enhances variations in the slopes of the spectral reflectance curves between the two different spectral ranges that may otherwise be masked by the pixel brightness variations in each of the bands.

Image Classification

Image classification is the process of creating a meaningful digital thematic map from an image data set. The classes in the map are derived either from known cover types (paddy, soil) or through algorithms that search the data for similar pixels. Once data values are known for the distinct cover types in the image, a computer algorithm can be used to divide the image into regions that correspond to each cover type or *class*. The classified image can be converted into a land use map if the use of each area of land is known.

Classification algorithms are grouped into two types of algorithms: supervised and unsupervised classification. With the supervised classification the analyst identifies pixels of known cover types and then a computer algorithm is used to group all the other pixels into one of those groups. With the unsupervised classification a computer algorithm is used to identify unique clusters of points in data space, which are then interpreted by the analyst as different cover types. The resulting thematic image shows the area covered by each group or class of pixels. This image is usually called a thematic image, or classified image.

Object Oriented Image Classification

The pixel-based classification approaches described in the previous section are based exclusively on the digital number of the pixel itself. Hence, only the spectral information is used for the classification. The conventional pixel-based approach primarily relies on the tone, color or spectral information of individual pixels, but the size, shape, texture, contextual and other type of information inherent in the image scene are ignored or not fully utilized and so its classification accuracy and reliability are often limited. The conventional classification approaches to image analysis produces a characteristic, inconsistent salt-and-pepper classification. This method is far from being capable of extracting objects of interest. It is able to carry out the classification parameter based only on the spectral properties of each band that is available in the image. The object-oriented approach, on the other hand, brings the supervised classification process into a polygon base. It makes the remote sensing data contents manageable by performing the segmentation process. Beyond that, additional information such as criteria, textual or contextual information of the segments can be described in an appropriate way to derive improved classification results. Hence, Object oriented classification output has proved to be more reliable than pixel based classification (Mansor et al., 2008).

Image Compression

A new algorithm for second generation wavelet compression has been proposed for TIN data compression (Pradhan et al., 2006). In various applications for a realistic representation of a terrain, a great number of triangles are needed that ultimately increases the data size. For online GIS interactive programs it has become highly essential to reduce the number of triangles in order to save on storage space. There is therefore a need to visualize terrains at different levels of detail, for example, a region of high interest should be in higher resolution than a region of low or no interest. Wavelet technology provides an efficient approach to achieve this. Using this technology, one can decompose terrain data according to hierarchy. On the other hand, the reduction iof the number of triangles in subsequent levels should not be too small as this could lead to poor representation of the terrain. We have proposed a new computational code for triangulated irregular network (TIN) using Delaunay triangulation methods (Pradhan et al., 2007). The algorithms have proved to be efficient tools in numerical methods such as the finite element method and image processing. Further, second generation wavelet techniques, popularly known as "lifting schemes", have been applied to compress TIN data. The new interpolation wavelet filter for TIN has been applied in two steps, namely splitting and elevation. In the splitting step, a triangle is divided into several sub-triangles while the elevation step is used to "modify" the point values (point coordinates for geometry) after the splitting. Subsequently, this data set is compressed at the desired locations by using second generation wavelets. The quality of geographical surface representation after use of the proposed technique as compared with the original terrain shows that this method can be used for significant reduction of data set.

INFORMATION FROM IMAGERY

The future of the remotely sensed data should ideally be in automated data processing and the development of robust and transferable algorithms for retrieving biophysical and geophysical parameters. A brief overview of the research work done at UPM is presented.

Land Use and Land Cover

Most traditional pixel-based classification approaches are based exclusively on the digital number of the pixel itself. Hence only the spectral information is used for the classification. As the conventional pixel-based approach primarily relies on the tone, color or spectral information of individual pixels, the size, shape, texture, contextual, and other type of information inherent in the image scene are ignored or not fully utilized. Hence, the classification accuracy and reliability is often limited. The conventional classification approaches to image analysis produce a characteristic, inconsistent salt-and-pepper classification. However, this method is far from being capable of extracting objects of interest. It is able to carry out the classification parameters based only on the spectral properties of each band that is available in the image. On the other hand, the object-oriented approach brings the supervised classification process into a polygon base. It makes the remote sensing data contents manageable by performing the segmentation process. Moreover, additional information such as criteria, textual or contextual information of the segments can be described in an appropriate way to derive improved classification results. Consequently, Object oriented classification output has proved to be more reliable than pixel based classification (Mansor et. al., 2008). Figure 7 shows SPOT-5 satellite image of Prai. Figure 8 is the land use derived for the study area.

Figure 7 SPOT-5 satellite image of Prai

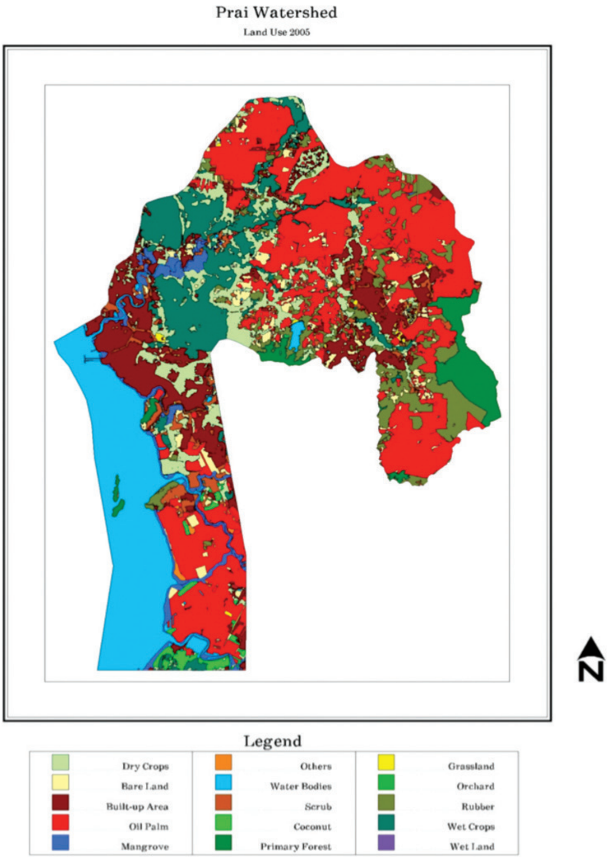


Figure 8 Land use map of Prai

Digital Elevation Model (DEM)

Digital elevation models (DEMs) are currently one of the most important forms of data used for various applications, Conventionally, DEMs are generated from contours, which are derived from aerial photographs using analogue and analytical stereo plotters. The introduction of the soft photogrammetry technique into the market has enabled other sources of data to be used to generate the DEM. This has greatly reduced dependency on aerial photographs as the only source of data as other data such as Spot Stereo and Ikonos high resolution data in optical domain can be used to generate DEMs. However, in the tropics, particularly in Malaysia, the occurrence of cloud cover throughout the year has made this technique unpopular. The recent advent of Synthetic Aperture Radar (SAR) technology has changed the dimension of generating DEMs from conventional stereo photographic techniques to techniques such as Interferometry, radargrammetry and inclinometry. These techniques are becoming more popular due to their capability to penetrate clouds, acquire data irrespective of time and most importantly, the accuracy achievable by the techniques have been proven to be acceptable by many user communities. We have developed an algorithm to generate DEMs based on SAR interferometry (Ku and Mansor 2003). The algorithm was tested using ERS, Radarsat data where the RMS for X, Y and Z were 6.8, 1.5 and 2.8 m respectively.

The use of existing spaceborne SAR data to generate DEMs in the tropical region is not very convincing as yet. It is not because of the limitations of InSAR technology but due to the characteristics of spaceborne data. Single pass data acquisition should ideally be the preference for this part of the world such that have been proven by the Airsar/Topsar Pacrim 1 and 2 missions over Malaysia in 1996 and 2000 respectively and the Shuttle Radar Topographic Mission (SRTM-2000). The possible solution is to have a satellite system with single pass data acquisition for InSAR single image or to develop techniques based on single image. One approach is Shape-From-Shading (SFS) (Clinometry). We have developed an algorithm to generate DEMs using the SFS technique. A new reflectance model for relating the radar SAR backscatter coefficient values to surface normal orientation was developed. Ground truth data in terms of ground control points (GCPs) are used to estimate the coefficients of the reflectance model and an iterative minimization SFS algorithm is implemented using this radar reflectance model to derive relative height measurements.

The relative SFS surface heights were computed using an iterative minimization SFS algorithm that involves the radar reflectance model proposed by Mobarak et al. (2010a) which, is given as:

$$R = \rho \frac{(\cos(\alpha_i))A^2}{(1-(\cos^2(\alpha_i))A^2)^{\frac{3}{2}}} \tag{1}$$

where, α_i is the incidence angle; ρ is the average radar backscatter and A is the illuminated area. The output from the radar SFS model is the relative heights. They are measured relative to the first pixel of the radar subset image which is located in the extreme upper-left corner. Due to the normalization of the reflectance model and the observed image intensity in the Fourier domain, the average heights of some parts of surface terrain could not be recovered. Further, the relative SFS measurements are scaled arbitrarily. Therefore, they need to relate to a specific vertical datum to provide significant results. To get such results, the relative height measurements from SFS were calibrated into absolute surface heights using the new model (Mobaraq et al., 2010b) represented by Equation (2)

$$H = A + Bx + Cy + Dz + E\sigma^\circ + F\beta^\circ \tag{2}$$

Where,

H is the calibrated absolute height values;

A, B, C, D, E, & F are the model coefficients;

x and y are the horizontal coordinates; z is the relative SFS height; σ° is the radar backscatter coefficient; and β° is the radar brightness.

The algorithm was applied to the RADARSAT-1 image. The performance of the algorithm was tested visually and numerically. Validation showed that the algorithm is promising, with an accuracy of RMSE and R^2, 25m and 0.967 respectively (Figure 9).

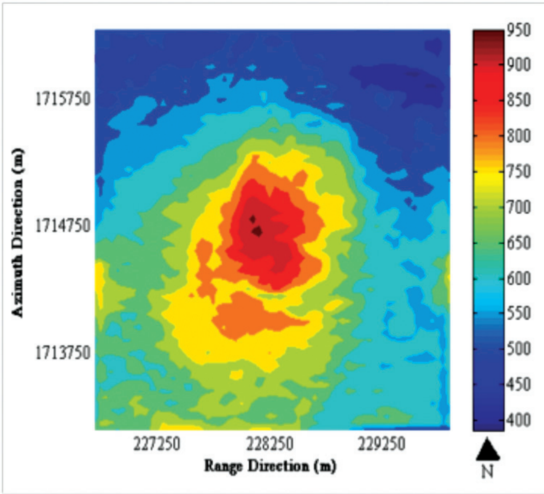


Figure 9 DEM from SFS

Sea Surface Temperature (SST)

AVHRR data has over the years of its existence proved very useful in providing near- real time data for the monitoring and detection of sea surface temperature (SST). The installation of an L-band ground station in ITMA, for the reception of NOAA-AVHRR data, has given the Spatial and Numerical Modeling Laboratory (SNML) the opportunity to develop a near real-time algorithm for estimating SST.

The major advantage of satellite sensors such as AVHRR is the ease and low cost of data acquisition. Inexpensive data, large coverage, daily planetary repeated coverage and composite imagery for sometimes cloud free scenes has made possible a reliable provision of near-real time coverage of large areas.

The algorithm based on radioactive transfer equations was used to extract sea surface temperature. The proposed model (Mansor et al., 2000) is defined as;

$$T_s = a_0 + a_1T_4 - a_2T_5 \qquad (3)$$

where T_s is sea surface temperature to be calculated, T_4 and T_5 are respectively the brightness temperatures of channel 4 and 5, a_0, a_1 and a_2 are coefficients which depend on the absorption coefficient of the atmosphere, emissivity and total amount of water vapor. The model was tested over AVHRR data (Figure 10) whereby the standard error of the estimated SST is within 1 degK.

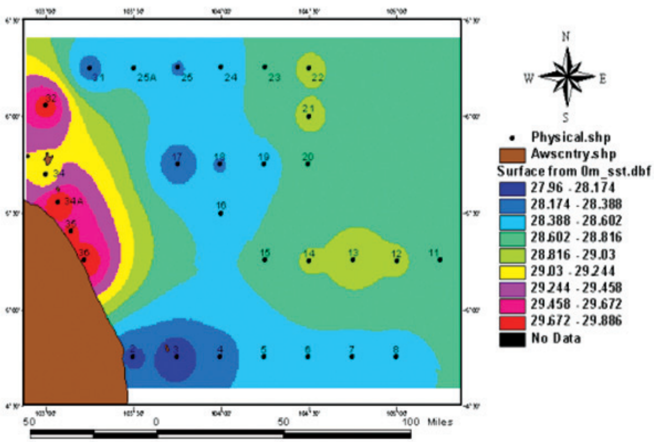


Figure 10 SST of South China Sea

Sea Surface Chlorophyll-a (SSC)

Mansor et al. (2000) have highlighted the need for an operational algorithm to extract chlorophyll-*a* for fish forecasting in Malaysia. No authority has as yet produced a chlorophyll-*a* map or phytoplankton map for Malaysian waters. In view of this problem this research focuses on developing algorithms for estimation of chlorophyll-*a* concentration because currently there is no operational algorithm to extract chlorophyll-*a* for Malaysian waters. The Remote sensing technique is a very useful tool for studying the distribution of chlorophyll-a concentration in a large water body area such as the Exclusive Economic Zone. The data from channel 2, channel 3 and channel 5 of SeaWiFS have been found to be the most suitable to extract the chlorophyll-a concentration. The strong correlation of radiance ratio corresponding to the above channels with in-situ data provided the basis for the development of the equation and constant for the estimated chlorophyll-a concentration in the South China Sea (Asmat et al., 2003). However, the use of satellite remote sensing for mapping chlorophyll-a concentration in the South China Sea is limited by the presence of cloud cover. Despite these disadvantages, satellite data are preferable as compared to field measurements if one's aim is to follow the temporal of phytoplankton over a large area. Saleh et al. (2010b) further developed the SSC algorithm for MODIS data. The equation is as follows:

$$SSC = \exp [\, a + b * \ln (R)] \tag{4}$$

Where $R = L_w 448 / L_w 551$; a and b are the coefficients.

Sea Surface Salinity

The following equation was developed for extracting SSS from the MODIS data (Salih et al 2010a):

$$SSS=28.1249+0.161925B1-210.996B2+13.9752B3+61.6833B4+147.686B5+1.21641B6-10.981B7+e \quad (5)$$

Where B refers to MODIS bands 1 to 7 and e is obtained from least square estimation of the sampling points. The equation was tested and validated using MODIS data acquired over the Semporna coast, South China Sea. The RMSE is < 1.5 psu.

Sea Surface Current

Much effort has been made to develop algorithms for derivation of wind vectors from SAR images. The wind speed is derived from the normalized radar cross section (NRCS), which is retrieved from the SAR data, using semi empirical C-band models for vertical (VV) polarization.

Mansor and Maiyas (2008) developed the CMODIFR2 model to be applied in the extraction of sea surface wind and current patterns from RADARSAT-1 SAR images. SAR wind field retrieval is a two-step process. The first step is to retrieve wind directions, which is an important input for the second step to retrieve wind speeds. The SAR wind speed retrieval is dependent on the accuracy of wind directions. Doppler shift frequency and nonlinear function were applied to extract the current speed and direction. They concluded that the CMODIFR2 model can be used to extract sea surface wind patterns from RADARSAT-1 SAR images with acceptable accuracy (Figure 11).

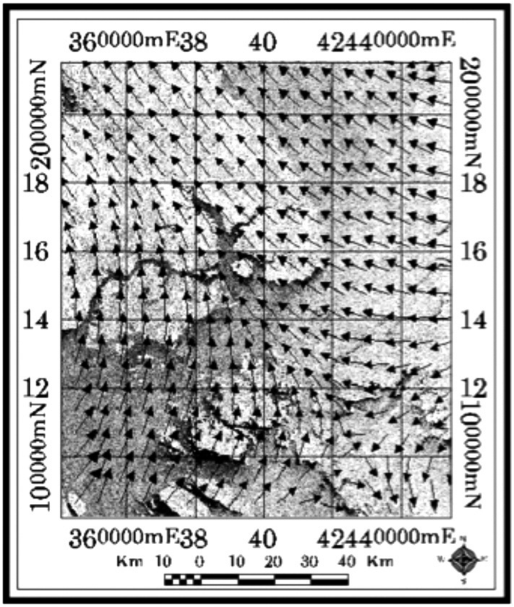


Figure 11 Wind pattern derived using CMODIFR2 wind retrieval model

A robust model has been developed to measure and extract the ocean surface current patterns (velocity and direction) from RadarSat-1 SAR imageries (Mansor and Maayas 2006). The model is as follows:

$$G(x_0,\omega)=H(\omega)e^{i\omega' x_0/V}\int_{-\infty}^{\infty}\exp\left[-\frac{2}{T_s^2}\left(1+\left(\frac{T_s}{T}\right)^2-\frac{ibT_s^2}{4}\right)\tau^2-\frac{4}{T_s}\left(\frac{x_0}{VT_s}+i\frac{\omega' T_s}{4}\right)\tau-\frac{2x_0^2}{V^2T_s^2}\right]d\tau \qquad (6)$$

where x_0 is the location of a point target in the SAR image, T_s is the Gaussian function with width, V is the satellite velocity = 6212m/s, τ is the delay time = $t - x_0 / V$ and $X_0 = vt$, and b is the chirp rate = $2kv^2 / R$

The model was applied to three different from RadarSat-1 SAR image modes (Wide3, HighExtended6, and Standard2). The energy spectra of the surface current, both inshore and offshore, can be estimated. The validation site is located between longitudes 102°50'00" to 103°40'00" East and latitudes 5°25'00" to 5°40'00" North, along the east coast of Kuala Terengganu. The RadarSat-1 SAR modes used in the study were Wide3, High Extended6, and Standard2 modes with accuracy validation (r^2). The validation accuracy (r^2) of the model was 75.3%, 72.6, and 86.3% respectively (Figure 12). These images had been acquired during the period 20-31 March 2005.

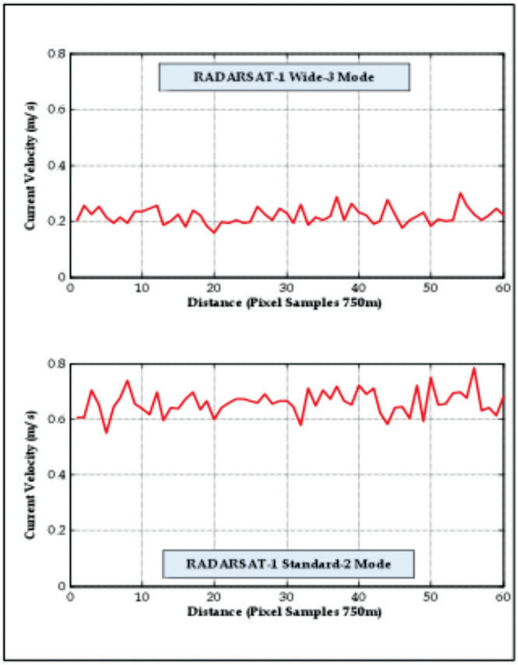


Figure 12 Sea Surface Current Velocity Simulated from RADARSAT-1 SAR Wide-3 and Standard-2 Modes in the Offshore Area

MODELS, MAPS AND MANAGEMENT

Maps are essential at all stages of the infrastructure development, resource planning and disaster management cycle. Satellite imagery can be used for everything from ground truthing and change detection, to more sophisticated analyses, including infrastructure planning and natural hazard prediction. As imagery has become more accessible and more affordable in recent years, there is also growing convergence of imagery and geographic information systems (GIS) applications to derive and describe the physical measurement process in sufficient detail, yet simple enough to allow robust inversion of the remotely sensed signals into thematic maps. These thematic maps are then used as an integral part of the spatial decision support system being developed. In this context convergence of imageries, information, models and maps is very critical. This chapter covers some of the research works done from infrastructure and resource planning to natural and technological hazard management.

Facilities and Asset Management

What is facilities and asset management? Another management initiative or just reworking of good old common sense? We have been managing assets for years, and the financial services world has long been using the term to mean "getting the best return from their investments". Nowadays, however, it is also being used to describe the professional management of physical infrastructure, of data and information, of people, public image, reputation and other types of assets. Oil companies, power and water utilities and other industries have recognised that despite all their cost-cutting, reorganisation, new technology, productivity and quality initiatives, the picture is fragmented. Inefficiency and conflicting objectives, lack of coordination and missed opportunities are still plentiful.

This is where facilities and asset management methods are needed – to make sure that the jigsaw puzzle is complete and the bits fit together. Facilities and asset management is the set of processes, tools, performance measures and shared understanding that glues the individual improvements or activities together.

In today's campus environment, maintenance managers must be able to accurately track and analyze operating and maintenance costs while taking advantage of opportunities to improve the reliability of facility and operations. Computerized maintenance management systems have become the backbone of such efforts in many facilities. A facilities management system (FMS) provides the capability to document, schedule and monitor the maintenance, repair and project costs associated with facilities and assets. It provides historical records of labour and material expenses on which maintenance and capital improvement budgets and manpower requirements can be based. Properly selected and implemented, the FMS is one of the most powerful tools in any organization. Further, with the proliferation of software options and their implications for other areas of facilities, managers face an even more important decision in selecting the "right" FMS. Selecting the most appropriate FMS must be an organized and precise effort, driven by the goal of implementing a system that will provide effective maintenance planning and history. UPM encountered two main challenges in delivering on the facilities management objectives – getting the people issues right and getting the system issues right.

Figure 13 (below) shows an overlay of linear assets (roadways) and non-linear assets (buildings) on an aerial photograph. This uniform way of visualization, identification and modeling of assets, irrespective of their type, aids in work planning, dispatch and execution.

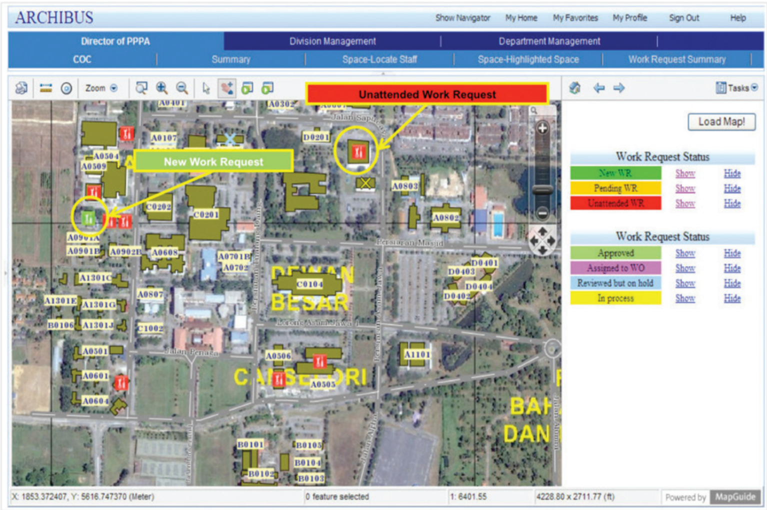


Figure 13 Linear and other assets on a projection map

Natural and Technological Disaster Management

Maps are essential at all stages of the disaster management cycle: prevention, mitigation, preparedness, response and recovery. It is important to undertake a range of activities such as: risk assessment; scenario analysis or analysis of consequences; forecast and projection; dissemination of information; allocation of personnel, equipment and other resources; the ability of relief personnel to reach various affected areas; damage assessment and so on (Mansor et al., 2004).. Maps play a critical role in all these activities. Hazard maps have been recognized as an instrument for disaster management in many countries in recent years. However, most of them are literally only maps indicating dangerous spots and not utilized for disaster reduction. It should also be noted that in many countries hazard maps developed by the national and local authorities are not distributed to the members of the community. The community must be provided with relevant information on hazard maps and on how to utilize them. Most importantly, how effectively hazard maps are used depends on the level of community awareness. The members of the community must be taught on how they can use these maps to understand the potential disasters in their area and to take appropriate counter measures.

In this section, discussion will be mainly confined to the analysis of the role of geoinformation technology in natural and technological disaster management. Satellite imageries and maps describe the locations of features on the Earth's surface. GIS is used to manipulate such data to create useful products and hazard maps while GPS receivers allow relief personnel to locate the affected area or injured residents. Remotely sensed imageries captured from satellite and aircraft provide the first comprehensive picture of an event's impact. Geoinformation tools are useful and indeed essential in all phases of disaster management. Yet it is never easy to persuade authorities or the general public of the need for investment in geoinformation infrastructure when the primary concerns in the immediate aftermath of an event are clearly focused on food, shelter and saving In year 2008 alone, natural disasters affected 214 million people, killed more than 235,000 and cost more than US$190 billion (Rodriguez et al., 2008).

Natural events cannot be prevented, but potential disasters can be 'managed' to minimise loss of life through a four-part cycle of mitigation, preparedness, response and recovery (Table 1).

Table 1 The four-part disaster cycle

• **Mitigation.** Long-term efforts to prevent hazards from becoming disasters or to make them less damaging. These include structural measures such as creating flood levees or reinforcing buildings, as well as non-structural measures such as risk assessment and land-use planning.
• **Preparedness.** Planning for when disaster strikes, including developing communication strategies, early warning systems and stockpiling supplies.
• **Response.** Implementing plans after a disaster. This includes mobilising emergency services, coordinating search and rescue efforts and mapping the extent of the damage.
• **Recovery.** Restoring an area, often through rebuilding and rehabilitation, then returning to mitigation measures.

Many types of satellites are used for earth observation but the area they see, and the frequency of observations varies. Two complementary types are particularly relevant to disaster management. Polar-orbiting satellites fly in a relatively low orbit (often at around 1000km above the ground), providing relatively high spatial resolution. However, they only collect data over the same point once every few days.

Geostationary satellites are positioned at a much higher altitude (about 36,000km). They orbit the Earth at the same speed as the Earth rotates on its axis, in effect remaining stationary above the ground and viewing the whole earth disk below. Their spatial data is much coarser, but is collected at the same point every 15 minutes. Each satellite carries one or more sensors on board that take measurements in different wavelengths. Many are useful for disaster monitoring — thermal sensors spot active fires and infrared sensors can pick up floods and subsurface fires (Mansor et al., 1994).

Landslides

Landslides or mass movements of rock and unconsolidated materials such as soil, mud and volcanic debris, are much more common than is generally perceived by the public. Many are aware of the catastrophic landslides, but few are aware that small slides are of constant concern to those involved in the design and construction business. These professionals can often exacerbate the problem of landsliding through poor planning, design, or construction practices. Frequently, the engineers are also forced into difficult construction or development situations as a result of ignoring the potential landslide hazard. This can be avoided if there is early recognition of the hazard and there is effective consultation between planners and the construction team prior to detailed development planning (Faisal et al., 2008)

Globally, landslides cause approximately 1,000 deaths per year with property damage of about US$4 billion. In Malaysia, landslides posed serious threats to settlements and structures that support transportation and tourism recently, causing considerable damage to highways, waterways and pipelines. Most of these landslides occurred on cut slopes or on embankments alongside roads and highways in mountainous areas while a few landslides occurred near high-rise apartments and in residential areas, causing death to human beings. The recent landslides which occurred near the North Klang Valley Expressway is a good example of the tropical landslides in Malaysia. In tropical countries like Malaysia most landslides are triggered by heavy rainfall.

In this section, the use of remote sensing data along with other tabular and meta data were used to delineate the landslide hazard mapping for Cameron Highlands. Terrain information such as slope, aspect, curvature, distance from drainage, geology, distance from lineament, soil, land cover, Normalized Difference Vegetation

Index (NDVI) and precipitation information have been updated to enable the quantification of landslide causative parameters. The qualitative landslide hazard analysis has been carried out using the map overlying techniques in GIS environment.

Case Study

The study area encompasses part of the districts in the Cameron Highlands which are experiencing rapid development with land clearing for housing estates and hotel/apartments, causing erosion and landslides (Figure 14). Cameron Highlands is located 30 km from Tapah, northwest of Pahang, and is a district in the Pahang state. This area is dominated by a sequence of mountains and hills as part of the Titiwangsa Mountain Range between 1280 and 1830 m above sea level. The study area covers an area of 660 square km and is located near the northern central part of Peninsular Malaysia. It is bounded in the north by Kelantan and to the west by Perak. Annual rainfall is very high, averaging between 2,500 mm to 3,000 mm per year. The area experiences two pronounced wet seasons from September to December and February to May. The maximum rainfall peaks fall between November to December and March to May when many landslides have been recorded along streams scouring the sides of the highlands.

The geology of the Cameron highland consists of mostly quaternary and Devonian granite. Geologically, this area consists of granitic rock with grain size ranging from medium to coarse. This rock is part of the main range granite, aged Late Mesozoic. The granitoid mountain range forms the highland areas with the highest point occuring at Gunung Brinchang (2030 m). The granitoid rock is part of the batholith intrusion, which forms the main range of the Malaysian peninsula. The geomorphology of the area consists of an undulating plateau stretching about 12 km towards the northern part of Peninsular Malaysia. The study area consists generally of high, rugged mountains and minor narrow intermontane riverine alluvial basins. The highlands are cloud-covered nearly throughout the year. The area is also mainly covered by dense tropical forest and some tea plantations, temperate vegetable and flower farms.

The Model

In this study, 1:25,000 scale aerial photographs were used to detect the landslide locations. These photographs were taken during the period 1981 – 2000, and the landslide locations were detected by photo interpretation and verified by fieldwork. Recent landslides were observed in aerial photographs from breaks in the forest canopy, bare soil or other geomorphic characteristics typical of landslide scars, for example, head and side scarps, flow tracks, and soil and debris deposits below a scar. To assemble a database to assess the surface area and number of landslides in the study area, a total of 324 landslides were mapped in a mapped area of 293 km^2.

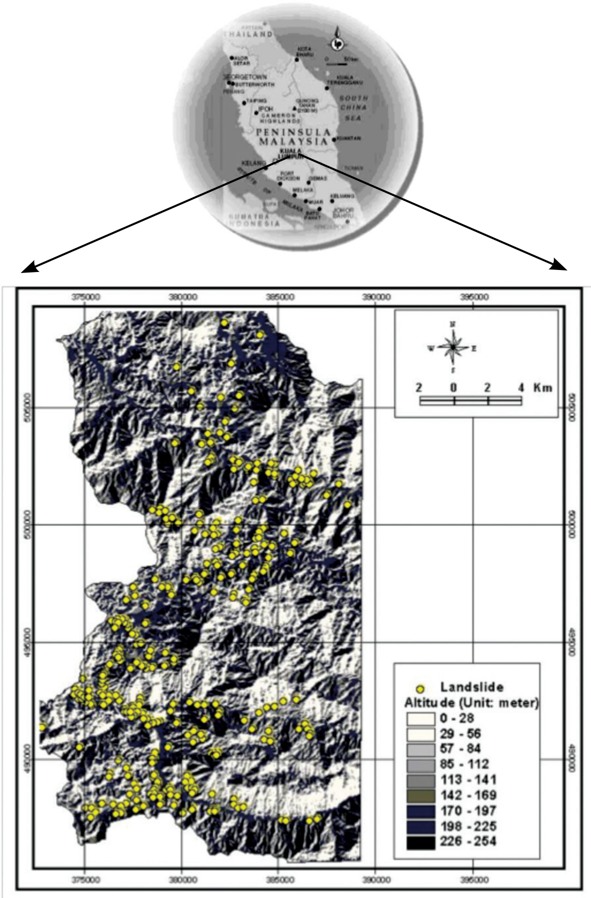


Figure 14 Landslide locations with hill shaded map of study area.

To apply the logistic regression model, a spatial database that considers landslide-related factors was designed and constructed (Pradhan et al., 2008). There were ten factors that were considered in calculating the probability, and the factors were extracted from the constructed spatial database. The factors were transformed into a grid spatial database using the GIS, and landslide-related factors were extracted using the database. A digital elevation model (DEM) was first created from the topographic database. Contour and survey base points that had elevation values from the 1:25,000-scale topographic maps were extracted, and a DEM was constructed with a resolution of 10 m. Using this DEM, the slope angle, slope aspect, and slope curvature were calculated. In the case of the curvature, negative curvatures represent concave, zero curvature represent flat and positive curvatures represents convex. The curvature map was produced using the ESRI routine in Arc View. In addition; the distance from drainage was calculated using the topographic database. The drainage buffer was calculated in 1m intervals. Using the geology database, the lithology was extracted, and the distance from lineament calculated. The lithology maps have been obtained from a 1:63,600-scale geological map from the Mineral and Geosciences Department, Malaysia. Further, lineaments were visually extracted using the SPOT 5 satellite imageries to complement the linear features obtained from the litho map. The lineament buffer was calculated in 1 meter intervals. The lineament buffer was calculated in 10 m intervals. The soil map was obtained from a 1:250,000-scale soil map. Land cover data was classified using a LANDSAT TM image employing an unsupervised classification method and topographic map. The land cover map was classified into six classes, such as Dense Forest area, Barren land, Agriculture, Rubber, Residential area (Concrete), Sparse Forest area and Residential area (Non-concrete), which were extracted for land cover mapping. Finally, the NDVI map was obtained from LANDSAT TM satellite images. The NDVI value was calculated using the formula NDVI = (IR – R) / (IR + R), where the IR value is the infrared portion of the electromagnetic spectrum, and the R-value is the red portion of the electromagnetic spectrum. The NDVI value denotes areas of vegetation in an image. Precipitation data was interpolated using the meteorological station data for the whole of Peninsular Malaysia over the last 20 years.

Subsequently, the calculated and extracted factors were converted to a 10m × 10m grid (ARC/INFO GRID type). Using the logistic regression model, the spatial relationship between landslide-occurrence and factors influencing landslides was assessed. The logistic regression mathematical equation was formulated as shown in equation (7).

$$\begin{aligned} z_n = &(0.0655 \times SLOPE) + ASPECT_c + (0.0494 \times CURVATURE) + \\ &(0.0007 \times DRAINAGE) + LITHOLOGY_c + (-0.0004 \times LINEAMENT) + \\ &SOIL_c + LANDCOVER_c + (-0.7563 \times NDVI) + (0.0155 \times PRECIPITATION) - \\ &64.1220 \end{aligned} \tag{7}$$

(where $SLOPE$ is slope value; $CURVATURE$ is curvature value; $DRAINAGE$ is distance from drainage value, $LINEAMENT$ is distance from Lineament value. NDVI, $ASPECT_C$, $LITHOLOGY_C$, $SOIL_C$, LANDCOVER$_C$ and $PRECIPITATION$ are logistic regression coefficients value listed in Pradhan et al. (2008) and z_n is a parameter).

The Landslide Hazard Map

Finally, the maps were verified and compared using known landslide locations and success rates and ratio areas were calculated for quantitative validation. The hazard map was then classified into 10 equal area classes in GIS. Out of the 10 equal area classes the first 10% was represented as "very high hazardous area" and the next 10% classified as "high hazardous area". Similarly, the remaining 40% of the total equal area was classified as "moderate hazardous area". Finally, the remaining 40% of the area was classified as "non hazardous area". The final classified hazard map is shown in Figure 15.

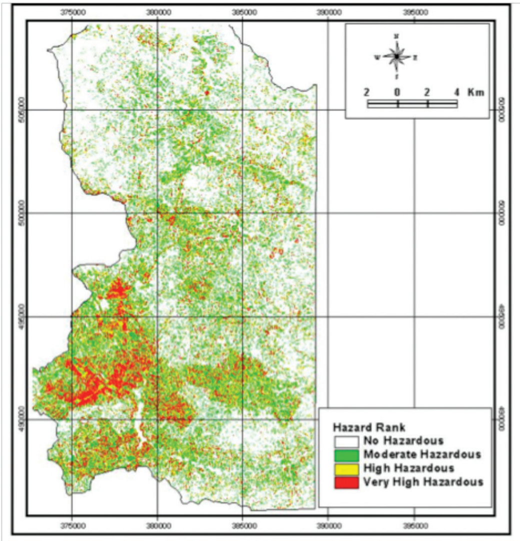


Figure 15 Landslide hazard map based on logistic regression model.

For validation of landslide hazard calculation models, two basic assumptions are needed. One is that landslides are related to spatial information such as topography, soil and land cover, and the other is that future landslides will be triggered by a specific factor such as rainfall. In this study, the two assumptions are satisfied because the landslides were related to the spatial information and the landslides were triggered by heavy rainfall in the study area. The landslide hazard analysis result was validated using known landslide locations. Validation was performed by comparing the known landslide location data with the landslide hazard map. In the case of the logistic regression model used, 90 to 100% (10%) class of the study area where the landslide hazard index had a higher rank could explain 51% of all the landslides. In addition, the 80 to 100% (20%) class of the study area where the landslide hazard index had a higher rank could explain 76% of the landslides. To compare the results quantitatively, the areas under the curve were re-calculated, whereby the total area is 1 which means perfect prediction accuracy. So, the area under a curve can be used to assess the prediction accuracy qualitatively. In the case of the logistic regression model used, the area ratio was 0.8573 and so we could say that the prediction accuracy is 85.73% (Figure 16)

Summary

In the present study, the logistic regression model was applied for the landslide hazard mapping for Cameron highlands. The validation results show that the logistic regression model has predication accuracy of 85.73%. The logistic regression model requires conversion of the data to ASCII or other formats for use in the statistical package, and later re-conversion for incorporation into the GIS database. Moreover, it is difficult to process a large amount of data in the statistical package. In the case of a similar statistical model (discriminant analysis), the factors must have a normal distribution, and in the case of multi-regression analysis, the factors must be numerical. However, for logistical regression, the dependent variable must be input as 0 or 1, therefore the model applies well to landslide occurrence analysis. Recently, landslide hazard mapping has been shown to be of great importance for suitable urban developments. The results shown in this paper can help developers, planners and engineers in slope management and land-use planning. However, one must be careful when using the models for specific site developments. This is because of the scale of the analysis where other slope factors need to be considered. Hence, the models used in the study are considered valid only for generalized planning and assessment purposes.

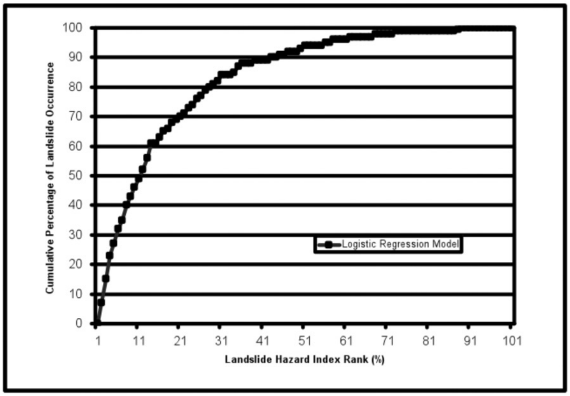


Figure 16 Cumulative frequency diagram showing landslide hazard index rank occurring in cumulative percent of landslide occurrence.

Floods

Floods are the most common of natural hazards that can affect people and infrastructure. They can occur in many ways. Riverine floods, the most prevalent, are due to heavy and prolonged rainfall. Other floods are caused by extremely heavy rainfall occurring over a short period in relatively flat terrain, high tides, excessive runoff and dam failures.

In South East Asian countries such as Malaysia, severe monsoon rainstorms some-times result in flash floods that strike quickly and in most cases without warning. Flooding is usually observed before any warning and usually people and properties are affected before any warnings can be issued. The consequences of these floods are economic loss, social disruption and sometimes loss of lives. Severe monsoon rainfalls are the most destructive natural disasters affecting Malaysia in respect of cost, damage to property and the extent of areas affected. The devastating tsunami of 26th December 2004 that caused huge causalities in some South East

Asian countries, including Malaysia, might make this statement arguable, but since the occurrence of tsunamis of this magnitude are rare and the chances of such occurrences are once in 50 years or more, monsoon floods still stand out as the most frequent and destructive natural disaster affecting Malaysia.

The basic cause of flooding in Malaysia is the incidence of heavy monsoon rainfall and the resulting large concentration of run-off, which exceeds the capacities of river systems (Ho *et al.*, 2002). Rapid urbanization within river catchments in recent years have also served to compound the problem with higher run-offs and deteriorating river capacity that increased flood frequency and magnitude. Various flood forecasting models and warning systems have been applied in Malaysia but they have proved inadequate due to their inability to predict impending floods and reduce the consequent economic costs of damage to lives and properties

Accurate and timely forecast of severe monsoon storms and early warning of floods are instrumental to the reduction of flood impacts. The damage caused by floods are generally associated with wind, storm surge and flooding. Forecasting of impending floods requires adequate hydro-meteorological information such as real-time rainfall, quantitative precipitation forecasts (QPF) and the cyclone landfall location. In the absence of quantitative estimates of local rainfall rates before the actual rainfall event, it is practical to get local precipitation data from satellites. Data from satellites can be processed for mesoscale rainfall as input into hydrological models through data assimilation for improved analysis and the provision of early flood warnings in advance of the flood event. Hence, close interaction of spatial meteorological technologies in the form of severe weather forecasting and hydrological modeling is important for improvement of operational flood forecasting and early warning and the consequent reduction in the impact of floods.

Ideally synoptic data are used to provide information on runoff and basin responses for flood forecasting, mostly with short lead times. However for a flood forecast to be really effective, a long lead time of forecast is necessary to provide enough time for contingencies. This can only be provided by meteorological satellite data processed to retrieve cloud information, determine local rainfall and predict flood disaster. Satellite remote sensing methods that are appropriate for operational weather forecasting rely on empirical relationships of thermal infra-red (TIR) and passive microwave imagery and/or rain gage GTS data (Xie and Arkin 1997). However, their success is limited by the indirect nature of the relationship of the observations to precipitation and the fact that they require calibration using gage data. The development of a flood early warning system therefore requires the integration of remote sensing, GIS and hydrological models for provision, monitoring and prediction (Billa et al., 2004).

Why Remote Sensing

Generally, remote sensing techniques are used to measure and monitor the areal extent of the flooded areas, to efficiently target rescue efforts and to provide quantifiable estimates of the amount of land and infrastructure affected. Then again remote sensing is also used for weather monitoring and quantitative precipitation forecasting to retrieve rainfall estimates. Incorporating remotely sensed data into a GIS allows quick calculations and assessments of water levels, damage and areas facing potential flood danger. Users of this type of data include flood forecast agencies, hydropower companies, conservation authorities, city planning and emergency response departments and insurance companies (for flood compensation). The identification and mapping of flood plains, abandoned river channels and meanders are important for planning and transportation routing.

AVHRR data of severe monsoon weather and of varying monsoon cloud formation can provide an understanding of cloud characteristics and rain bearing tropical storms. AVHRR data is preferred for this study because of the easy acquisition, relatively high spatial resolution, cost effectiveness and its ability for automated geometric correction when compared to GOES and GMS data. It also has a better spectral resolution of five channels compared to the three of other meteorological satellite data. NOAA data has relatively high temporal resolution of not more than 6 hours daily. This is however less frequent when compared to the hourly reception of GMS and GEOS data. The challenges are to utilize pre real-time or the earliest AVHRR data cloud observations together with a suitably developed QPF model to improve short-range severe monsoon weather forecasts as input for "Nowcasting", where nowcasting is defined as flood forecasting in the approximate range of 0-9 hours from observation time.

Flood Early Warning System

The conceptual design of the proposed flood early warning system can be found in Billa et al. (2004). It incorporates meteorological satellite image processing for mesoscale rainfall using pre real–time NOAA-AVHRR data whereby Grid based rainfall intensity is developed as input for flood forecasting.

The second part of the system is a MIKE 11 NAM rainfall-runoff (RR) and a one-dimensional hydrodynamic modeling process for rainfall-runoff, discharge and water level simulation. Various hydrographs are developed from the modeling process. As a part of the MIKE 11 hydrological system the RR model is used for automatic system calibration and also for the simulation of rainfall runoff based on a carefully prepared river basin model.

Part three of the system is the platform for hydrological GIS development. The river basin and catchment delineation are performed here using spatial modeling techniques and tools in GIS. Apart from the collection, preparation and storage of hydrological data such as land cover, contour, settlement and other flood data, the basin surface digital elevation model (DEM) and the river channel geometry are developed in this section using 3D modeling techniques and manipulations of the integrated GIS model. The results of the runoff and hydrodynamic simulation are imported and coupled with the DEM for flood mapping. The flood mapping process is based on the expected precipitation over the basin and sub-watersheds and also on the assumption that floodwater follows the physical constrains of the terrain as it rises. Settlement and critical facilities are overlaid to assess the extent of the flood in relation to these data and a resulting inundation map generated.

Case study : Langat River Basin

The system was tested on the Langat river basin based on an enactment of the severe flood event of 27th September 2000. The Langat watershed area is to the southeast of Selangor state and approximately 27 km to the south east of Kuala Lumpur. The basin area is situated within latitudes 101° 43'E to 101° 58'E and longitudes 02° 59'N to 03° 17'N. It falls under the administrative district of Hulu Langat in the eastern part of the Malaysian peninsula. It is bordered to the south by the district of Sepang and in the west by Kuala Lumpur. Upper Langat area has two major dams, the Langat dam located on the Lui tributary and the Semenyih dam on the Semenyih tributary. These dams, together with the upper Langat catchment area, make up one of the important domestic water supply sources for the approximately 1.9 million population of Kuala Lumpur and the surrounding areas (Wong *et al*., 2002).

Rainfall Estimates Based on Reflectance and Brightness Temperature (T_B)

Empirical studies over the years have established that cloud top temperatures less than 235°K in the tropics generally produce stratiform rainfall at the rate of 3 mm/hr (Arkin and Meisner, 1987). AVHRR data for daytime pass was processed for cloud top reflectance and brightness temperature (T_B). The multi-spectral channels provided by the AVHRR data proved useful in this processing. Raw digital numbers (DN) of channels 1 and 2 of the data in level 1B-format were converted to channel top of atmosphere (TOA) reflectance and thermal channels 4 and 5 to radiance .The tests for reflectance and T_B are shown in Figures 17 (a) and (b) respectively. The values of reflectance are graphically displayed on a color scheme ranging from pink to blue as shown in the processed image, while the processed T_B of channel 4 is shown on the scheme of high T_B in yellow and low T_B in pink.

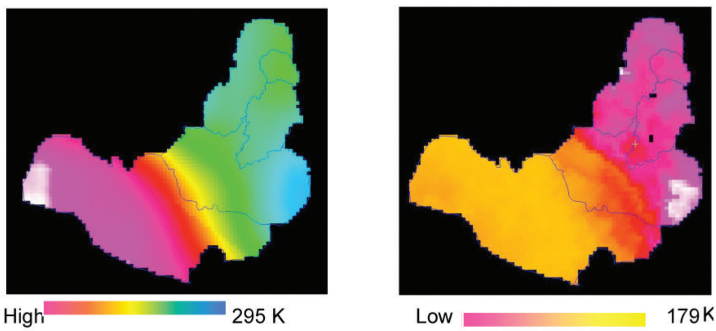


Figure 17 (a) Reflectance (*Refl*) (b) T_B [°K] of Langat river basin

High Cloud Classification and Screening for Non-precipitating Cloud

The AVHRR data was further investigated to establish cloud base height using the combination of channels 1, 2 and 4 and visual interpretation techniques. A supervised classification was performed using the nearest neighbor sampling method to discriminate clouds into high, middle and low clouds heights. This process is important so as to delineate and isolate the higher most clouds for further processing. The high cloud classification was used as the basis for a zonal mean cloud-screening test. The screening for non-precipitation cirrus cloud is performed based on an established empirical discrimination of thin cirrus temperature on a slope plane (Adler and Negri, 1988), where the local minima in the T_B are sought and screened to eliminate thin, non-precipitating cirrus.

Clouds with temperature below 235 ^{o}K threshold values were taken as indication of instantaneous rainfall. At this temperature, high clouds begin to condense and precipitate. The grid based rainfall and dimensions of rain bearing cloud pixels were measured after a mask had been applied to scale the rainfall model for the Langat basin and catchment level. Rainfall intensity was determined by K-means classification that grouped cloud pixels with T_B below the established threshold into mean clusters. Rainfall rates were assigned to the K-means classes to show intensity (Figure 18) based on the assumption that every rainfall pixel has a beginning unit rain-rate of 3mm/hr, which from empirical studies is appropriate for tropical precipitation over +/-3^{o} areas around the equator. The mean clusters were assigned rain rate values from 3-12 mm/hr depending on how low the T_B of the cluster is below the 235 ^{o}K. The total cold cloud cover and the portion of the catchment covered by cloud pixels determine rainfall coverage and the intensity.

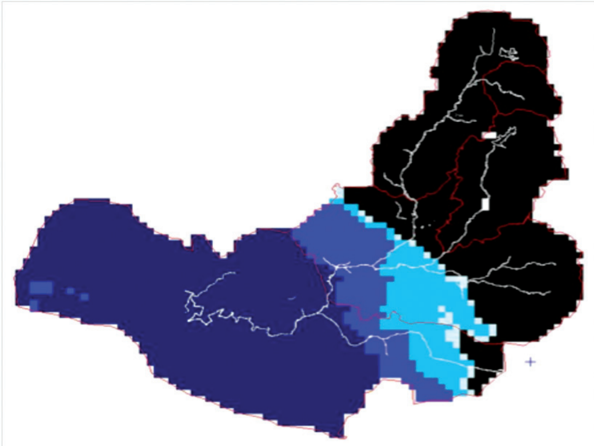


Figure 18 Rainfall intensity based on K-mean classes

Rainfall-Runoff and Hydrodynamic Modeling

Rainfall runoff is performed based on the NAM (RR) model which is part of the MIKE11 River modelling system. It is one of the lumped conceptual models widely applied in hydrological modelling for simulating the rainfall-runoff processes at catchment scale. As the parameters of the model cannot generally be determined directly from the catchment characteristics, the parameter values must sometimes be estimated by calibration against observed data.

The hydrodynamic (HD) simulation in MIKE11 is based on an efficient numerical solution of a complete non-linear St. Venant equation for the 1-D flow. The systems network editor assists in the schematization of the river system and flood plain as a system of inter–connecting branches. The flood level and discharges are calculated at specific points along the branches as a function of time to describe the passage of the flood flow through the model domain.

Rainfall Runoff (RR) Simulation

The rainfall-runoff simulation involves preparation of the Langat River Basin parameters using the MIKE 11 basin work module. The Basin was delineated into main sub-catchments using a registered topographical map. The mean area rainfall distribution was computed and generated based on Theissen's polygon. Rainfall runoff simulation was carried out using the NAM lumped distributed model and results generated graphically in different runoff hydrographs. The model is appropriately calibrated for the basin to ensure good agreement between the observed and simulated data. Two sets of data were used in the rainfall-runoff modeling process to ensure good comparison. The calibration included in the model is shown in:

1. Observed hourly data of rainfall and discharge of the flood event of 27 Sept. to 08 Oct. 2000 (Figure 19).
2. Computed rainfall data based on the developed QPF model by using hourly GMS data for the same flood event of 27 Sept. to 08 Oct. 2000 (Figure 20).

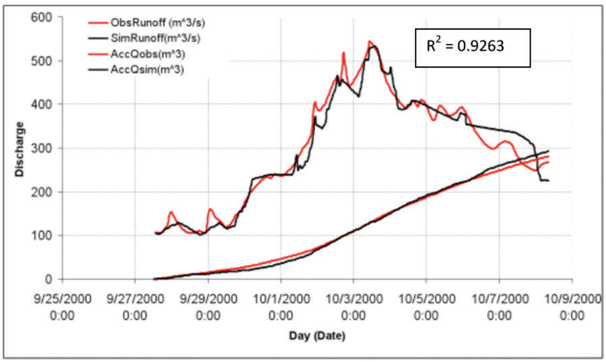


Figure 19 Rainfall-Runoff and Accumulated Discharge (Calibration for Kajang Catchment Based on Observed Data)

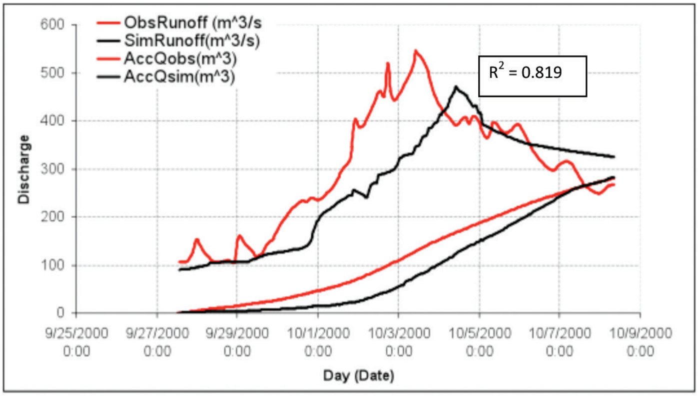


Figure 20 Rainfall-Runoff and Accumulated Discharge (Calibration for Kajang Catchment Based on QPF Rainfall)

Hydrodynamic (HD) Simulation

Hydrodynamic simulation involved the development of the Langat river network model and linking all tributaries in MIKE 11. The river and tributaries cross sections were also developed (Figure 21). Boundary conditions were prepared and entered for both the upper and lower ends of the river section. Overall, 22 rivers and sub river cross-sections were entered for the Langat river basin model. Hourly water levels and discharge data collected were prepared in a compatible MIKE 11 time series format as input to an open boundary type. Observed hourly water levels and discharge data of the flood event were used in the HD simulation.

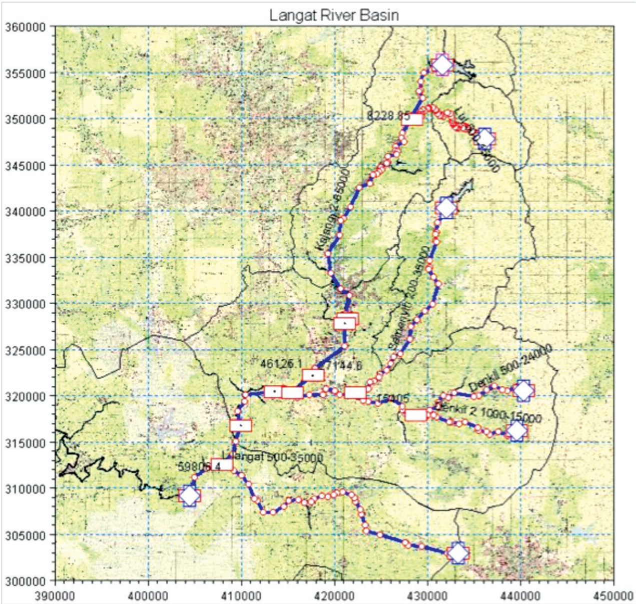


Figure 21 Integrated Langat River Model

Hydrological GIS and Flood Mapping

The hydrological GIS was developed using an integrated MIKE 11 GIS in ArcView 3.2 GIS environment. This allowed the easy importation of MIKE11 calibrated results to be combined with the developed Langat Basin DEM for flood map development. The data developed in the GIS included the road network, river network, settlement, contours for surface terrain development and past flood data point coordinates of flood locations in the flood event. The generation of flood inundation maps is an essential part of flood forecasting and early warning systems. The integrated MIKE 11 GIS provided the essential platform for operational purposes of the early warning process. The basin DEM was imported as a grid file to the flood management module (FM), where it was integrated with the rainfall-runoff and hydrodynamic results of the hydrological modeling.

In the FM module the DEM provides an understanding of the surface elevation of the study area from which flood depth can be extrapolated, whilst runoff and hydrodynamic results provide the automated rainfall-runoff process and flood distribution modeling. Settlement data and other critical facilities were overlaid to visualize and assess the impact of the given flood period. Other ancillary information such as flood extent and depth were deduced from the flood map to facilitate flood impact assessment and contingency planning.

Figure 22 shows the resulting flood area map for the Langat River basin for the simulation period. Buildings and settlement features were generated in the DEM to determine the extent of the flooding. The flood map produced forms the basis for early flood warning in areas likely to be inundated within a given catchment area.

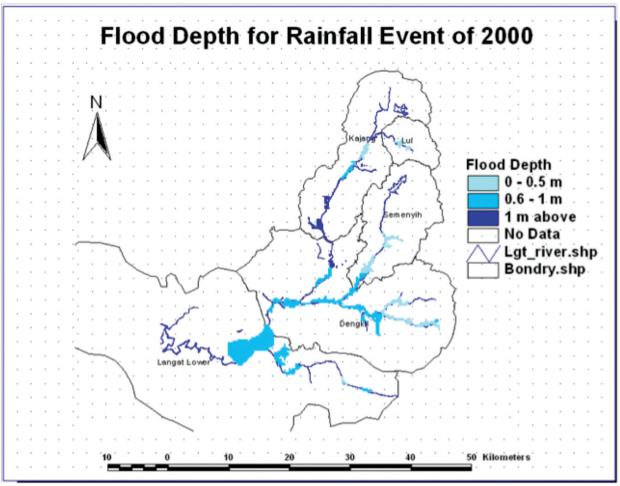


Figure 22 Flood Areas for the Simulation Period

Summary

A comparison of runoff hydrographs generated from the observed rainfall with QPF estimated rainfall showed a high coefficient of determination of R2 = 0.9028. In using rainfall intensity range of 3 - 12 mm/hr, the QPF model was able to replicate the flooding of the storm of 27 September to 08 October 2000, within comparable extent. Using the NAM RR model with suitable calibration coefficients, rainfall-runoff simulation was performed to establish the coefficient of determination (R^2) for both observed and QPF generated rainfall. The runoff hydrograph of the observed data showed $R^2 = 0.896$ between observed and simulated rainfall whilst the hydrograph for QPF generated rainfall showed $R^2 = 0.850$. Although observed rainfall is not as exact as estimated rainfall, both showed comparable flood area coverage in the flood simulation for the flood event. Flood maps generated before an actual flood storm are useful early warning tools for flood emergency and contingency planning. Certain factors can however impact the accuracy of flood maps, such as, the quality of elevation data used in the DEM development, detailed river cross-section and flood plain data and the distribution of rainfall data in the modeling process (Billa et al., 2006).

Forest Fire

Satellite images such as the Landsat Thematic Mapper, SPOT and ERS-SAR combined with low-resolution satellite images such as NOAA-AVHRR and MODIS have been used operationally to monitor forest fires. Remote sensed images also offer capabilities for detecting new wildfire starts, monitoring ongoing active wildfires, and, in conjunction with fire-weather forecasts, providing an early warning tool for escalating, extreme wildfire events (Mansor 2009).

Forest fire and the resultant smoke-haze are increasing in intensity and recurring periodically. Most of the forest fires reported in Malaysia occurred in degraded or logged-over peat swamp forests, both in the east and west coasts of Peninsular Malaysia and the coasts of Sabah and Sarawak. One of the important aspects in eliminating forest fires is the prediction of potential fire hazard areas by preparing the fire hazard maps that can be derived from GIS-based modeling. Fatal damage by forest fire could be reduced if there is suitable prediction and rapid provision against forest fire with the usage of GIS, remote sensing technology and computer modeling.

Forest Fire Detection

Fire detection using remote sensing techniques is not a particularly difficult task except for the effectiveness of the sensor used in relation with the minimum size detected and according to the fire's effective temperature. The study of forest fires through remote sensing techniques has been limited to the cartography of burned areas in cases where real time work is required, and to the assessment of the spreading risk when being operative is required. On the other hand, fire detection is a necessity which will not be solved until geostationary satellites prove their capability to detect small fires and show their usefulness in providing early alert warnings, which will be really difficult considering the difficulty of building high spatial resolution thermal sensors. The most relevant conclusion with respect to the current use of spatial sensors for fire detection is that so far it has been used only for the elaboration of fire occurrence mapping and to obtain statistical results.

With respect to the sensors used to carry out fire detection, the most important one without doubt has been the NOAA-AVHRR sensor, thanks to its higher time resolution and to the type of sensors it has.

MODIS produces global fire maps that show active fires over the past ten days (see Figure 23). This active fire mapping system is used by a wide array of fire monitoring programmes, including Sentinel Asia, the Global Fire Monitoring Center and the regional visualisation and monitoring system, SERVIR, that covers Latin America and the Caribbean.

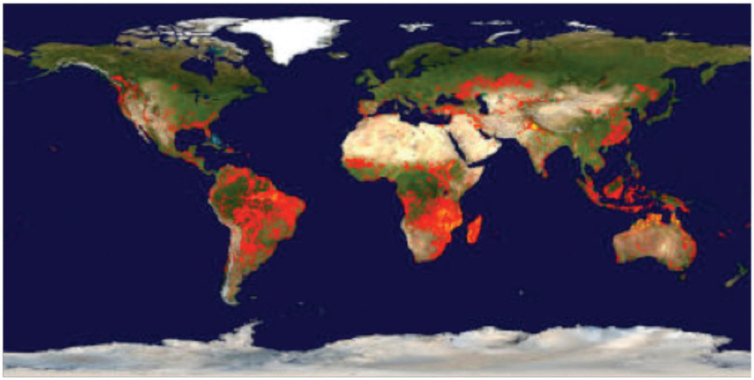


Figure 23 MODIS global fire map 9–18 August, 2009

Forest Fire Hazard Map

Millions of dollars are spent annually on protecting life and property, timber, recreational areas and valuable wildlife habitats. The need for accurate and timely information is crucial for safety and resource protection. There are at least two factors that have to be taken into account in estimating how large the problem of forest fires actually is. First is the number of forest fires. However, the number of forest fires gives us only limited knowledge. Hence, secondly, it is necessary to know how large the total area burned in forest fires year by year is. When these two factors are combines the average size of a fire can be estimated. These two factors indicate how large the problem is and how our system, consisting of measures for prevention, detection and extinguishing, should work. The operational use of satellite data and GIS for forest fire management has four aspects: fire hazard prediction; fire monitoring; inventory of fire damage to forests and assessment of losses; monitoring of recultivation and reforestation efforts. In general, there are two kinds of decision aids required in fire management. The first is a predictive model to identify potential fire problems that may occur, and the second is an operational decision-aid tool (or action plan) to reduce or prevent the impact of serious fire situations.

It is impossible to control nature but is possible to map forest fire risk zones and thereby minimise the frequency of fires. Various fire hazard models and techniques have been developed, that explore the dynamic and static factors for model variables in a bid to provide information on fire susceptibility and the potential area that will be affected.

In Malaysia, an application of Remote Sensing and GIS for forest fire prevention has been attempted by Patah *et al*., (2002), and Pradhan & Arsad (2006). Patah *et al*., (2002) had developed a model using the integration of remote sensing and GIS to produce Fire Risk Index (FRI) maps which could be modified interactively with changing weather conditions. The Forest Canopy Density (FCD) model was applied to the satellite imagery to better differentiate forest fuel types from other ground vegetative fuel types as well as to estimate the percentage of canopy density. The computation is based on four indices – Advanced Vegetative Index (AVI); Bare Soil Index(SBI); Shadow Index (SI) and Temperature Index (TI). FRI maps are relevant for fire management - prevention and suppression. It can help the relevant authority to design regional fire defense plans, which include fuel management practices in drought conditions and design of firebreaks and watch-tower location for Fire Disaster Preparedness.

The Model

A GIS-grid-based fire hazard model was developed to determine the level of severity of wildfire hazard zones in terms of mapping vulnerability to wildfire by assessing the relative importance between wildfire factors and the location of fire ignition (Setiawan, *et al.*, 2004). A spatially weighted index model was used to develop the fire hazard model as follows:

$$H = 0{:}432V + 0{:}289PR + 0{:}135A + 0{:}108S + 0{:}045E \qquad (8)$$

where V, PR, A, S and E are coefficients applied to vegetation, proximity to roads, aspect, slope and elevation.

Combining elevation, dangerous topographic features, slope, aspect and fuel type into one raster data set accurately classifies the danger of forest fire hazards in the area. After the probability grid map was created, a final fire hazard assessment map was generated by multiplying all of the scoring factors with the weighting value derived from the AHP method, as shown in the above equation.

Pekan District in southern Pahang, Malaysia was selected for this study because it faces an annual forest fire problem. The total area is about 83,992 ha, most of which is covered by peat swamp forest (85,218.41 ha or 46.21 percent), with the rest being wetland (50,519.54 ha or 27.39 percent), arable land (22,395.58 ha or 12.14 percent), lowland forest (20,467.96 ha or 11.10 percent) and mangrove forest (4,108 ha or 2.23 percent). At the beginning of July 1997 this area was seriously affected by a dense haze arising from local wildfires in the peat swamp forest. There were about ten reported hot spots of wildfire occurrence in the study area during that time. Wildfire destroyed a PSF area totaling approximately 1,600 ha.

A mosaic Landsat TM scene was used to extract land use parameters of the study area. A triangle irregular network was generated from the digitized topographic map to produce a slope risk map, an aspect risk map and an elevation risk map. Potential of peat swamp forest fire hazard areas were identified and mapped by integrating GIS-grid-based and multi-criteria analysis to provide valuable information about the areas most likely to be affected by fire in the Pekan District, south of Pahang, Malaysia.

Fire-causing factors such as land use, road network, slope, aspect and elevation data were used in this application. Spatial analysis was applied to reclassify and overlay all grid hazard maps to produce a final peat swamp forest fire hazard map. The final fire hazard map is displayed in Figure 24. The final map of the fire hazard zone showed that about 49,678 ha or 27 percent of the total area is categorized as facing very high fire risk, at 10.76, 41.73 and 20.51 percent, respectively, being in the categories of high, moderate and low risk.

To validate the model, the actual fire occurrence map was compared with the fire hazard zone area derived from the model. The results show that most of the actual fire spots are located in very high and high fire risk zones identified by the model (Setiawan, *et al*., 2004). Comparison of the predicted fire hazard zone map and the map showing actual occurrence of hot spots recorded in 1997 in the study area (Figure 25), showed that most of the actual hot spots are located in areas categorized by the model as being very high and high fire risk zones. It can be concluded that the model provides valuable information about the areas most likely to be affected by fire.

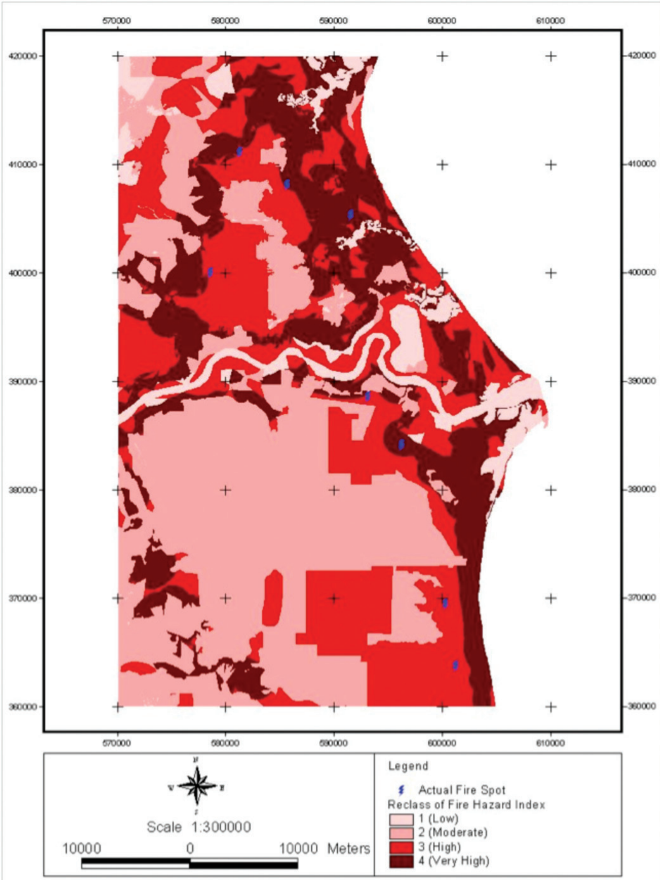


Figure 24 Potential Fire Hazard Map

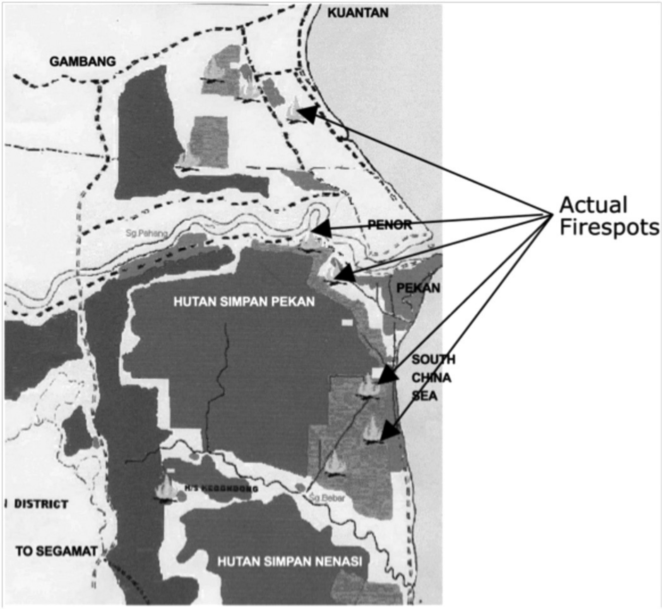


Figure 25 Actual fire spots in the study area, 1997

Geohazard Sinkhole Map

Subsurface geological fractures in karst terrain are often associated with unpredictable environmental and geotechnical engineering problems. This requires precise mapping and an understanding of the distribution of geological fractures on multi-scales. To extract and investigate surface and subsurface geological fractures on such multi-scales, we can use VNIR or SAR imageries (Samy et al., 2009). The integration of visual interpretation and topographical fabric algorithm is capable of extraction and spatial correlation of subsurface geological fractures. This method was applied to the Kuala Lumpur and Ipoh limestone bedrock in Malaysia, by focusing on the adjacent mountainous areas and the geometries and bathymetries of ex-opencast mining ponds. The spatial correlation of the extracted surface geological fractures was clarified by rose diagrams, semivariogram models and a confusion matrix. Spatial correlation shows that the Malaysian peninsular, surface and subsurface geological fractures and the geometry of ex-opencast mining ponds share similar trends. The results obtained using this methodology are compared to the subsurface geological fractures reported by means of geophysical survey and field investigation. This proposed method may be useful for mapping geological fractures in areas of high soil moisture where geophysical survey is difficult and/or not available and is also highly applicable in other parts of Malaysia or south east Asia, permitting better understanding of the geotectonics and geotechnical engineering setting of the study area.

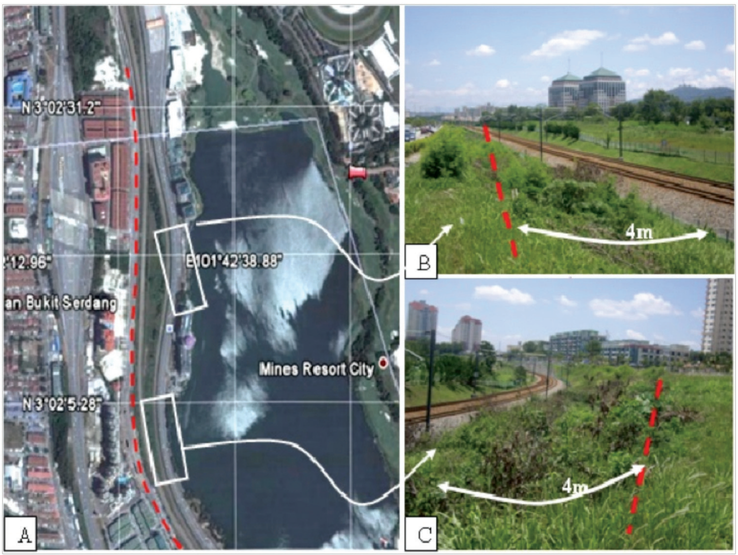


Figure 26 Flank geometry (zigzag pattern) and bathymetry of ex-opencast mining ponds (A), cut slopes (slope breaks or fault displacements, C) and vegetation stress (B) are good sources of geological information for subsurface fracture extraction and analysis

Geostatistical analysis was for investigation of the nature of spatial variations of karst terrain using the GIS (Omar et al., 2010).

The study focuses on using aerial photography for the detection of changes and effects of mining on geomorphology. In addition, the distinctive surface topography of the karst landscapes can be characterized in order to compare them with non-karst landscapes, and to determine geological and/or climatic conditions that are responsible for the observed terrain of the Kinta Valley Limestone formation in Perak, Malaysia. Geostatistical analyses of the karstic terrain are used in order to distinguish between karst and non-karst areas to observe the variation from the deterministic sample. In contrast, if the range is less, that means the average distance between two points that are similar in height is less and therefore there is more variation in the area. The average range for karst areas is 435, while the average range for non-karst areas is 690 meters. The difference between the major range and minor range, which indicates the degree of anisotropy, is higher for the karst area and this is an indicator of more variations in spatial structure and auto correlation of the karst elevation. Figure 27 shows the geohazard risk map developed for the study area.

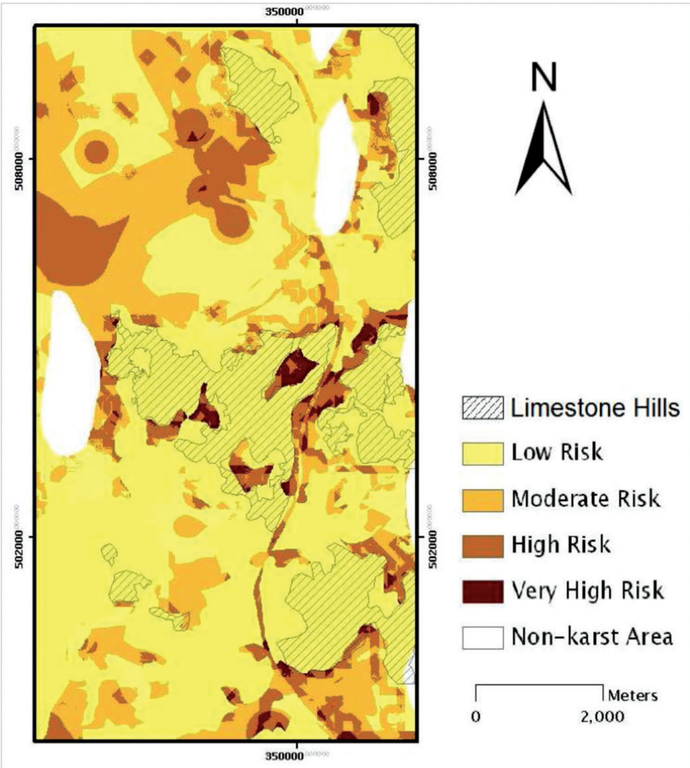


Figure 27 Geo-risk map of study area.

Earthquakes

Earthquakes are particularly difficult to predict. Tectonic activity is the main cause of destructive earthquakes, followed by earthquakes associated with volcanic activity. Where the history of earthquakes due to seismic activity is available for an area, the faults associated with the activity can frequently be identified on satellite imagery.

This section describes the work done related to earthquake prediction (Aman et al., 2010). The study involved interpreting the historical record of earthquakes and body wave (mb) in the Zagros

Mountains(ZM) (1909 –2007). The study area lies approximately between 27°N to 36°N in latitude and between 45°E to 57°E in longitude. The main trend of the ZM in West of the Iranian plateau is NW-WS, 300 km wide and extends for about 1500 km from eastern Turkey to the Straits of Hormoz.

The study shows that seismo-neotectonic activities in the west of Iran are not only irregular variations but also temporal regular changes. Frequency of earthquake, mb, geology and rocks play an important role in interpreting seismo-neotectonic activities in the Zagros Mountains in Iran. The results can be used to infer and understand the seismo-neotectonic activities and be used to predict earthquake occurence.

Earthquake frequency and distribution of monthly and annual occurrence of earthquakes for the period of 1909 to 2007, was compiled. Trend and intercept coefficients of the quantitative variables such as earthquakes were determined and analyzed by square least method. Both frequencies of the earthquakes, yearly and monthly, and their diagrams were analyzed and illustrated in GIS environment. The geostatistical data illustrate changes in seismo-neotectonic activities in the region. These changes have been fundamentally caused by plate tectonics movement.

The following relationship can be established to indicate earthquake growth rate for the Zagros Mountains;

$$\text{Ln (Frequency of Earthquake)} = \text{C (intercept)} + \text{T (Trend)} + € \tag{9}$$

where (€) is the residual effect.

Oil Spill Detection, Monitoring and Contingency Planning

Oil spills can destroy marine life as well as damage ecologically valuable species and habitats. The Malaysian coastal and marine environment is enriched by a wealth of economically and ecologically valuable species and habitats that are severely threatened by increasing oil spill incidences from passing vessels especially along the Straits of Malacca. The majority of marine oil spills result from ships emptying their billage tanks before or after entering the port. Large area oil spills result from tanker ruptures or collisions with reefs, rocky shoals or other ships. These spills are usually spectacular in the extent of their environmental damage and generate wide spread media coverage. Remote sensing, GIS and GPS tools are used for oil spill detection, monitoring and contingency planning (Assilzadeh et al., 2003).

The key operational data requirements are fast turnaround time and frequent imaging of the site to monitor the dynamics of the spill. For spill identification, high resolution sensors are generally required, although wide area coverage is very important for initial monitoring and detection. Although airborne sensors have the advantage of frequent site specific coverage on demand, they can be costly. Further, spills often occur in inclement weather, which can hinder airborne surveillance.

SAR sensors can image oil spills through the localized suppression of Bragg scale waves. Oil spills are visible on a radar image with a darker tone than the surrounding ocean. The detection of an oil spill is strongly dependent upon the wind speed. At wind speeds greater than 10 m/s, the slick will be broken up and dispersed, making it difficult to detect. Another factor that can play a role in the successful detection of an oil spill is the difficulty in distinguishing between a natural surfactant and an oil spill. Multi-temporal data and ancillary information can help to discriminate between these two phenomena.

To facilitate containment and cleanup efforts, a number of parameters can be derived from the remotely sensed imageries:

1. Spill location
2. Size and extent of the spill
3. Direction and magnitude of oil movement
4. Wind, current and wave information for predicting future oil movement
5. Coastal sensitivity index

For ocean spills, remote sensing data can provide information on the rate and direction of oil movement through multi-temporal imaging, and input to drift prediction modelling and may facilitate in targeting clean-up and control efforts. Remote sensing devices used include the airborne visible and infrared photography, thermal infrared imaging, airborne laser fluouro sensors, airborne and spaceborne optical sensors, as well as airborne and spaceborne SAR. SAR sensors have an advantage over optical sensors in that they can provide data even under poor weather conditions and when it is dark.

Case Study

On 16 October 1997 at 2100 hours a collision occurred between two oil carriers in the Straits Of Singapore and caused the worst oil spill in Singapore's history. The vessels involved in the collision were MT Evoikos and MT 0rpin Global. An estimated 25,000 metric tons of marine fuel oil spewed into the sea from MT Evoikos as a result of the damage from the collision. The oil spill spread into the surrounding waters and islands. Within four days of the collision the oil slick reached Pulau Hantu, Pulau Senang, Pulau Pawai, Pulau

Sudong and seemed to be moving into the Straits of Malacca. The oil was also moving slowly towards Tanjung Piai under the influence of the current. A large patch of oil was found 4 n.m off Pulau Pisang and 4 n.m off Tanjung Piai. The oil slick moved north westerly into the Straits of Malacca forming an elongated shape due to the strong current flow through the narrow gap between Tanjung Piai and Pulau Karimun Besar. The oil was in the form of a thick slick with minimum effect of wind.

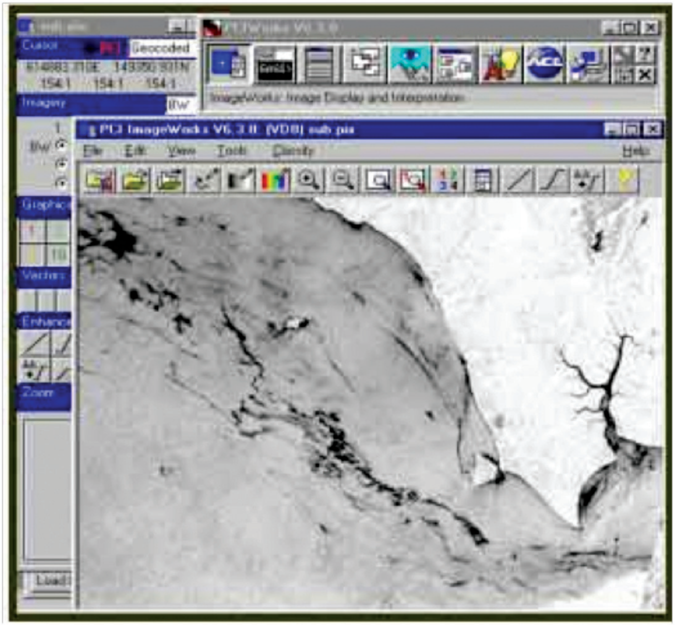
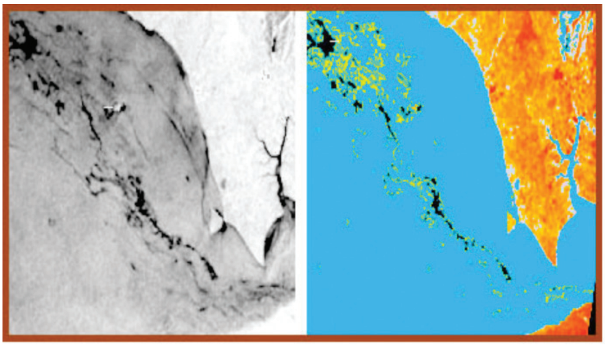


Figure 28 Radarsat image

In this Radarsat image (Figure 28) taken a week after the spill, the extent of the oil spill is visible. The dark areas off the coast represent the areas where oil is present. Oil, which floats on the top of water, suppresses the ocean's capillary waves, creating a surface smoother than the surrounding water. This smoother surface appears dark in the radar image. As the oil starts to emulsify and clean-up efforts begin to take effect, the capillary waves are not as effectively damped and the oil appears lighter. Size, location and dispersal of the oil spill can be determined using this type of imagery.

Classified radar imagery can be used to estimate the statistical information of oil spills such as volume, length, distribution and thickness (Figure 29). The ESI map (Figure 30) serves as a quick reference for oil and chemical spill responders and coastal zone managers. The ESI map contains three types of information. (i) Shorelines which are color-coded to indicate their sensitivity to oiling; (ii) Sensitive biological resources, such as seabird colonies and marine mammal hauling grounds which are depicted by special symbols on the maps; and (iii) important human-use resources, such as water intakes, marinas and swimming beaches.



a) b)

Figure 29a SAR image processing for oil spill detection in the Straits of Malacca (a) processed data after gamma filter distribution analysis on the image (b) classified image

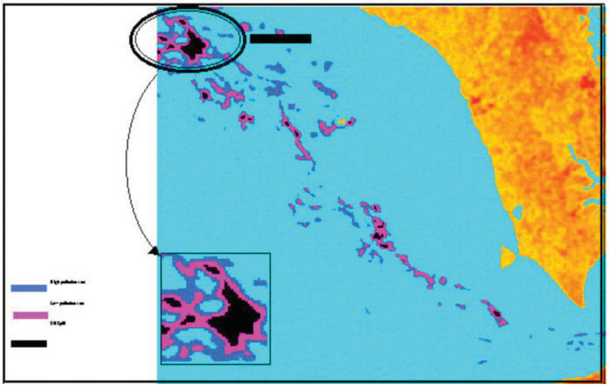


Figure 29b Oil spil classification: black colour is spill area, red is high pollution area and blue is low pollution area

Oil Spill Trajectory Simulation

In any oil spill emergency response the short-range trajectory modeling studies are the most important; and therefore it should be done in real time to give day- to -day support to oil spill contingency plans for a specific spill. On entering water, oil undergoes a complicated multi-process phenomenon. The sum of all of these processes is called weathering. Weathering includes, in the order of approximate occurrence, spreading, evaporation, dissolution and emulsification, auto-oxidation, microbiological degradation, sinking and resurfacing. While these processes are occurring, the oil slick continues to drift, under the influence of winds and ocean currents. The most important and well known among the weathering processes is the spreading and drifting, which occur simultaneously.

Based on historical oil spill records, hypothetical spill trajectories could be simulated based on ground data and meteorological information for each of the potential launch areas in the sea environment. The results could then be presented and assessed in each of the four seasons of the year from each launched area as the simulation part in a contingency plan.

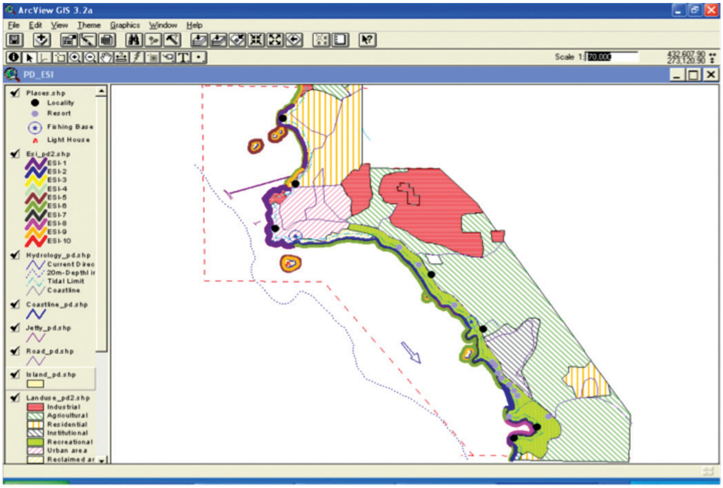


Figure 30 ESI map

Oil Spill Contingency Planning

A successful combating operation in relation to a marine oil spill is dependent on rapid response from the time the oil spill is reported till it has been fully cleared. In order to optimize the decision support capability of the surveillance system, a GIS database should be integrated with the detection tool. Information on the exact position and size of the oil spill can be plotted or visualized in a GIS environment and priority combat efforts and means, according to the identified coastal sensitive areas, can be carried out. The system can also offer opportunities for integration of oil drift forecast models (prediction of wind and current influence on the oil spill) for risk assessment. An effective response to a marine oil spill requires knowledge of the sensitivity of the coastal zones to enable determination of the priorities of combat activities, to protect the most sensitive areas. Primary data should be available for the study area such as historical data of oil spill incidents. This includes information on the incident date, location and sources of oil spill, types of spillage, width of oil spill and the effect of the spillage on the coastal environment. Apart from the base map, other data includes shoreline natural resources, coastal land use, response team information, oil spill response capability and equipment, port location and meteorological data. Raster and vectorised spill data, environmental sensitive areas and the aforementioned information will then be used for trajectory modelling and risk assessment and contingency planning.

Decision Support System for Coastal Prioritization

Prioritization is one of the powerful approaches in coastal area management planning and strategies, in relation to oil spill management (Pourvakhshouri and Mansor 2003). A 180 km shoreline of two states in west Malaysia, Negeri Sembilan and Melaka, was chosen to examine the prioritization through decision support system. Priority criteria had been selected based on local experts' knowledge in relevant domains. Coastal data acquisition was based on Malaysian ESI maps which had been validated by remote sensing data as well as field checks and Coastal prioritization ranking had been done according to coastal sensitivities. The Main required criteria for classification of the coastal sensitivities against oil pollution were defined according to the experts' knowledge. The local data was updated by area visits and field validation, and key points were located on the image and map from GPS readings. These points and features were transferred to remotely sensed images and GIS-based maps as well as linked to related information and databases, obtained from the Department of Environment and the Fisheries department, to establish an updated ESI map. The information extracted from image was transferred to GIS to obtain the vector maps for more analyses. Then the rules for running the DSS of oil spill management were prepared based on the local and non-local experts' knowledge. If-based rules of Visual Basic programming assisted in developing a user friendly engine and interface.

The main goal achieved was with regards to the establishment of a "priority ranking scale" for the coastal area, assisting the decision making procedure for management of coastal threats. According to this ranking, any risk area will be categorized into different, important areas; whether the area faced direct impact on human activities and life or not. The factors for direct impact were defined and were discussed with various people, including officers and responders. In the case of direct impact on human activity, the coastal area will be prioritized as high priority for protection and management. If the area is not under the direct impact potential group, it will go through the coding process to determine its level in the priority ranking scale.

Although all the coastal areas received a code and number for ranking, they were finally categorized into five main categories from extremely critical to low priority. It was made simple and understandable by all users through description of the category and reference to the management alternatives, which come up through the DSS management recommendations (Pourvakhshouri et al., 2004).

Natural Resources Management

Biodiversity Richness Index

Malaysia is recognized as one of 12 mega biodiversity countries in the world. In this research project, Matchinchang, Langkawi was selected as the study area due to its excellent geo-diversity, which has shaped its landscape related bio-diversity over decades (Mansor 2008). The overriding objective was to develop a spatial model for generalized plant bio-richness characterization, which would be useful for bio-conservation planning. Researchers under the project have developed remote sensing based techniques to map bio-indicators (forest and non forest, forest communities, bio-disturbance, species diversity and terrain complexity). Spatial processing tools like the Maximum Likelihood Supervised Classifier, Spatial filtering, Patchiness index, Shannon-Weaver Index, and Digital Elevation Model were used to generate the forest communities, bio-disturbance, plant species diversity and terrain complexity layers respectively. Field samplings were also conducted to collect ground information on plant species numbers using Differential Global Positioning System (GPS). The researchers also adopted the Analytical Hierarchical Process (AHP) to develop an appropriate model to map the bio-richness of the study area. Geographic Information System (GIS) was used to generate the plant bio-richness map through spatial modeling. The methodology developed in this research shows promise despite its generalized nature and can be exploited for rapid plant bio-richness assessment in other forested parts of Malaysia (Yanti et al., 2010).

The model for bio-richness is given as:

$$BR = 0.539 \; SD + 0.297 \; BD + 0.164 \; TC \qquad (10)$$

where BR is the bio-richness index, SD is species diversity, BD is bio disturbance and TC is terrain complexity. The sub-criteria scores for SD, BD and TC are tabulated in Yanti et al. (2010).

Potential Fishing Zone

The Outline Prospective Plan (OPP3) unveiled by the government has targeted that the agricultural sector (including the fishery) will be the third engine of growth, with emphasis on the fisheries industry, particularly deep sea fishing and aquaculture to be further developed on a commercial and integrated basis, adequately supported by modern fishing infrastructure, processing, marketing, network, comprehensive human-resource development and R&D programs. The development plans focus on resource utilization on a sustainable basis.

Set in the era of ever-decreasing resources and increasing demand, modern fishing methods require that development of offshore fishing fleets be complemented by accurate forecasting of fishery stocks. The efforts presently spent on fish finding can now be more effectively directed towards the process of fish capture and preservation at sea. Setting of fish aggregating devices could also be done in areas of known fish stock congregations thereby providing greater chance for large catches for the fleet. Fishery managers can also use this information for fish planning actions to protect depleted fish stocks.

In order to catch fish efficiently, understanding fish behaviour represents the earliest attempts at fish forecasting. Since the 1900's studies on fishery and fish stocks has developed in relation to development of capture fishery. Studies on the migration of fish and its relationship with oceanographic conditions, modeling of fish populations, determination of fish stocks and the total allowable catch (TAC) further underline man's quest to understand fish behaviour so that management of the fishery industry can be achieved based on firm scientific basis and sustainable development can be achieved for future generations (Tan et al., 2002).

Satellite Fish Forecasting

The use of satellite remote sensing to provide synoptic measurements of the ocean is becoming increasingly important in fisheries research and fishing operations. Variations in ocean conditions play a key role in natural fluctuations of fish stocks and in their vulnerability to harvesting. Information on the changing ocean is necessary to understand and to eventually predict the effects of the ocean environment on fish populations. The evolving capabilities of satellite sensors and data processing technologies, combined with conventional data collection techniques, provide a powerful tool towards the development of fish forecasting and management techniques.

Since the launch of the TIROS/NOAA meteorological satellites in the 1970s, synoptic measurements of the sea surface temperature through AVHRR sensor have been routinely studied in the US. The launch of the SEASAT in 1978 brought the first satellite specifically designed for and dedicated to ocean surveillance through the Coastal Zone colour scanner (CZCS). Today the range and variety of satellites built to exacting requirements, developed to survey the colour, temperature, surface height and roughness parameters of the sea, are operated by many nations, including Japan for MODIS/ADEOS, Taiwan for the OCTS and IRS for India. Generally the equipment used has become progressively more sophisticated, enabling greater spectral and spatial resolution. This in turn has led to greater utility of remote sensing as a viable data-gathering medium (Meaden and Thang, 1996). Development of a fisheries information and advisory system for Japan has now made it routine for fishing vessels to receive advise on ocean colour and sea surface temperature for most registered fishing vessels on demand.

The development of fish forecasting models for temperate and high latitude fishery however could not be directly applied to our tropical regions. This is due to differences in fish species, and thus their behaviour, and environmental conditions of the different oceans.

A major project involving several objectives and phases to meet the goal of developing a satellite-based fishery forecasting system in the South China Sea is aimed at supporting the national aspirations of developing an efficient offshore fishery sector. More importantly, it is aimed at providing the basis for alternate ways to meet the goals of sustainable harvest of fishery resources. The project is now completed, with most of the major objectives met. Project deliverables include an efficient algorithm for the extraction of sea surface temperature (SST), sea surface salinity (SSS) and sea surface chlorophyll (SSC) for tropical regions (Salih et al., 2010, Mansor et al., 2000). A model for determination of potential fishing zones(PFZ) has also been developed (Salih et al., 2010). The model is as follows:

$$\mathbf{PFZ = \alpha 0 - \alpha 1\ (SST) + \alpha 2\ (Depth) + \alpha 3\ (SSC) + \alpha 4\ (SSS) + e} \qquad (11)$$

where,

α0, α1, α2, α3 and α4 are the coeifficients, and
ε is the residual

Although this model has been field tested with good results, its application in real time mode will depend on availability of real time satellite data for SST, SSS, and SSC, and the development of a web based fishery information system to disseminate PFZ and other oceanographic information to registered users.

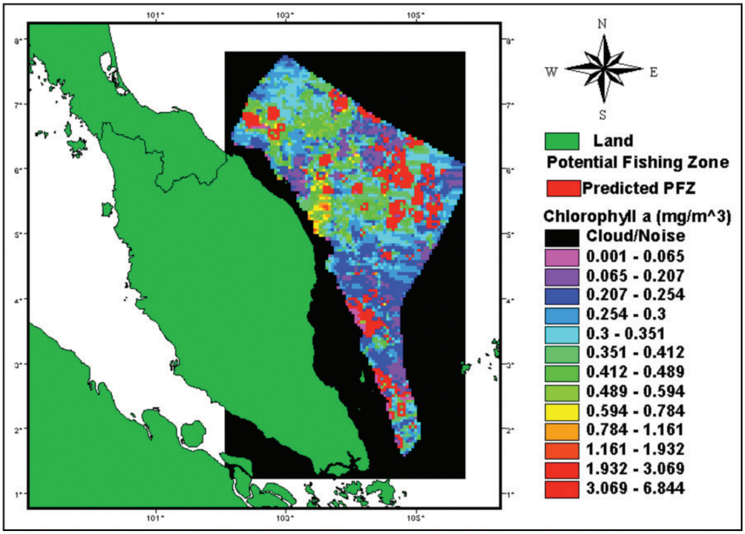


Figure 31 Potential fishing zone map for 21 to 27 September 2000 (MODIS)

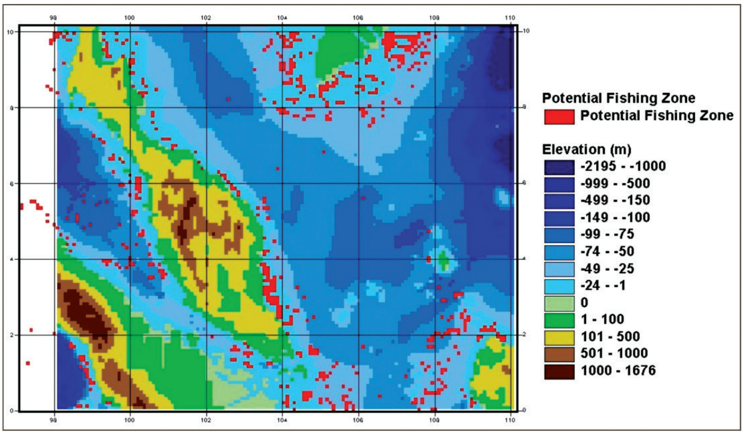


Figure 32 Potential fishing zone map in relation to bathymetric depth

Oil Palm Plantation Management

There is a high demand for rapid and accurate oil palm tree counting not only for more efficient oil palm plantation management but also for reliable valuation of oil palm estates for the real estate, banking and insurance industries. Currently tree counting is done manually by estate labourers or via visual digitization of the palm trees from satellite imagery, by professionals. These techniques are time consuming and are subject to human error. We have developed remote sensing based spatial tools for automatic oil palm tree counting for 5 palm age groups, which were 2, 5, 10, 15 and 18 year old palms (Wan Zanariah et al., 2010). The acquired QUICKBIRD imagery was first treated with a specially designed 15 x 15 smooth filter to delineate the dome shaped palm tree crowns, subsequently a 7 x 7 edge enhancement filter was used to delineate the inner high intensity diameter of the palm crowns and finally the individual palm centroids were marked out using an image threshold technique.. It was observed that the centroids of the palms were well separated for all age groups except for the 2 year old palms, attributed to mixed reflections from both the palm fronds and the leguminous cover crops. The centriods were then vectorized for automatic counting in a GIS`. The accuracies obtained for the 2, 5, 10, 15 and 18 age groups were 96.4, 99.1, 98.8, 98.7 and 98.1% respectively. In the GIS, these centroids were essentially point files of individual trees, where attributes such as age, plant condition, yield and production cost were incorporated, thus establishing a palm tree inventorying system. This system is useful for plantation managers, most importantly for evaluating crop performance, evaluating reliability of planting materials and evaluating the plantation’s market value.

THE FUTURE OF IMAGERY

Sensing the Earth has proven to be a tremendously valuable tool for understanding the world around us. Over the last half-century, we have built a sophisticated network of satellites, aircraft, and ground-based remote sensing systems to provide raw information from which to understand past, current and future changes on the Earth. Through remote sensing, knowledge of the Earth and how it functions has expanded rapidly in the last few decades. Applications of this knowledge, from natural hazard prediction to resource management, have already proven their benefit to society many times over. As demand for such information grows exponentially; what will remote sensing be like a decade from now and what new capabilities will there be?

Mass-market consumer applications are emerging that will radically transform our use of Earth information over the next decade. Advanced sensor technologies will allow us to view the Earth in three dimensions at nested spatial scales. Further, vast networks of sensors will bring the most remote corner of the world into our daily lives and Internet geospatial portals and geographic search engines will put all of this information at our fingertips. GPS-based devices which are now widely employed for car navigation, Internet maps and virtual worlds (such as Google Earth and Microsoft Virtual Earth) enable everything from education to vacation planning to real-estate hunting while mobile phones provide a ubiquitous distribution platform for location-based information. The substantial thrust is in doing things faster, cheaper and better. Spatial and temporal sampling in the non-visible portions of the spectrum (particularly infrared and microwave) will improve with time. Further, with the growing demand, novel sensor approaches are also likely to appear. One such possibility is in "interactive remote sensing," where farmers genetically "tag" crops to enhance the remotely detectable spectral signature for crop monitoring.

An area which will receive much attention is imagery constellation where data providers are able to weigh various collection assets, either satellite, aerial photgraphy or UAV, to deliver the requirements of customers. With more than one high-resolution satellite available, customers are guaranteed not only more coverage of the planet, but more frequency and accuracy. The combination of more satellite revisits with aerial imagery also enables a time-sequenced, precision image that is down to six centimeters. In a nutshell, a constellation of imagery assets provides the currency, resolution, and accuracy that facilitates response to any developing situation. Coupled with historical archived data and aerial assets, a constellation can easily show the changes that have occurred over time and monitor areas of interest that are specific to a given customer. In the future customers will be able to subscribe to their areas of interest, search archives for existing data, order and collect data based on collection frequencies of their choice.

Community Remote Sensing is an emerging field that combines remote sensing with citizen science, social networks and crowd-sourcing to enhance the data obtained from traditional sources to enable better stewardship of our planet. It includes the collection, calibration, analysis, communication, or application of remotely sensed information by these communities. Indeed, data supported and provided by people and sensors “on the ground” will provide much fuller insight for projects around the world, such as disaster management and emergency response.

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BIOGRAPHY

Shattri Mansor was born in Kampung Raja, Padang Matsirat, Langkawi, Kedah in 1960. He obtained his early education at Kelibang Primary School and Mahsuri Secondary School. He then completed his secondary school education at Sultan Abdul Hamid College, Alor Setar. He studied surveying at Universiti Teknologi Malaysia where he obtained his B.Sc. degree in 1984. He then joined Universiti Pertanian Malaysia (UPM) as a Tutor at the Department of Civil and Environmental Engineering. Then he proceeded with his Master Degree in Engineering Surveying & Geodesy at the Department of Civil Engineering, University of Nottingham, United Kingdom. He was employed as a lecturer at the Department of Civil Engineering in 1986. Subsequently, he did his PhD in the Department of Applied Physics, Electronic and Manufacturing Engineering, University of Dundee, on "Quantitative analyses of thermal infrared satellite data for geophysical investigations". Dr. Shattri was promoted to Professor in 2005. He is currently the Director of Development at Universiti Putra Malaysia.

Dr. Shattri has taught a total of 10 subjects at Postgraduate, Bachelor and Diploma levels. He has been contributing continuously to the development of various engineering programmes, curricula and syllabi during his 25 years of service as tutor, lecturer, associate professor and professor at the Faculty of Engineering. His most recent and valuable contribution is as the key person developing the Master of Science programme in the area of Remote Sensing and GIS. He was the pioneer and coordinator or the MS (Remote Sensing and GIS) programme that now has an enrollment of over 70 students from ten countries. Being a proactive researcher, he was entrusted with the task of setting up the Spatial and Numerical Modeling Laboratory in 1999, under the Institute of Advanced Technology, UPM.

Dr. Shattri has been the leader in acquiring and completing several major research projects with a total funding of RM 3.0 million from the Ministry of Science, Technology and Innovation (MOSTI). Dr. Shattri maintains diverse research interests including image processing, remote sensing and GIS. His major research effort includes feature extraction from satellite imagery, spatial decision support system, fish forecasting, oil spill detection and monitoring system, UAV-based remote imaging, disaster management and early warning systems. As a result, hundreds of his works have been recognized and published extensively in renowned journals and conference proceedings. He has also been an invited speaker and panelist at various conferences. In tandem with his expertise, Dr. Shattri has also supervised and co-supervised a total of *22 MS students, 24 PhD students and 6 post doctorates*. He is also an external examiner for students from other higher learning institutions, for their MS/PhD degree.

Dr. Shattri holds membership to various organizations and institutions. He is currently the Co-Chairman for the International Society of Photogrammetry & Remote Sensing (ISPRS) Working Group II/7, an *executive committee member* for the Institution of Surveyors Malaysia (ISM Geomatics and Land Surveying Division), a member of the *National Committee* on Mapping and Spatial Data, a *technical advisor* for the development and implementation of the Malaysian Geospatial Data Infrastructure, a member of SPIE and a member of the National Working Group on Route Information, Guide Signs and Addresses. He has served as a *councilor* for the Institution of Surveyors Malaysia (ISM), as an *Editor* for the Malaysian Surveyor Journal and as an executive committee member for the Malaysian Remote Sensing Society. He is currently an Editorial Board member of the Malaysian Journal of Remote

Sensing and GIS, Disaster Advances Journal and International Journal of Geoinformatics.

In University Putra Malaysia, Dr. Shattri had served on more than 40 committees, was also a key committee member and conference chairman of more than 10 major conferences, and also held various administrative posts. He is currently the chairman of the Asset Management Committee and the Infrastructure and Traffic Committee.

In summary, Dr. Shattri is a well-rounded person. As an academician he is very effective and excellent in his teaching. He also participates actively in research. As a leader he manages and leads his group and organization towards commendable achievements. He has received several awards at the international and national levels, including 2 Gold Medals at the Malaysian Technology Expo (2006), Gold Medal at ITEX Geneva (2005), Gold Medal at IPTA Exhibition (2005), Bronze Medal at EUREKA (2005), *Best Article Award (2000),* Silver Medal at the National Expo of Science & Technology (2001 & 2003) and several awards at UPM level, including the UPM Excellence Research Award (2003 & 2005) and UPM Excellent Service Award (1996 & 2001).

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1. Development Of An Integrated Biodiversity Support System At Landscape Level
2. Development Of An Early Warning System For Monitoring Water Catchments
3. Application of RS & GIS Technique in Fish Forecasting
4. Low Cost Real Time System for Detecting Hydro Carbon
5. Airborne Interferometric and Polarimetric Radar Analysis for Resource and Environmental Application
6. Expert System for Routing & Siting
7. E- Spatial Tool for Digital Earth
8. Oil Spill Contingency Planning System
9. Integrated Monitoring System for Disaster Management
10. Wave Spectra
11. Development Of A Spatial Multi-Criteria Decision Support Tool For Oil Palm Plantation Management
12. Flood Zone Mapping Using Satellite Imageries

The following projects were funded through FRGS, RUGS and UPM research grants:

1. Mobile Fish Finder

2. Development of Artificial Neural Network and Advanced Fuzzy Logic Model for Mapping, Monitoring & Mitigation of Landslides
3. Determination of Geophysical Parameters from Space

The writer also acknowledges the contributions of research colleagues at the Spatial and Numerical Modeling Laboratory (ITMA) and Faculty of Engineering and his graduate students. Materials included in this lecture are from the collection of knowledge published in their dissertations, journals, seminars, conferences and workshops.

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