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BUILDING EOS CAPABILITIES FOR MALAYSIA: THE OPTIONS

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ABSTRACT

Earth observation satellite (EOS) is currently a major tool to monitor earth dynamics and increase human understanding of earth surface processes as well as atmospheric dynamics. Since the early 1980s, Malaysia has been a user of EOS images in various areas of applications, such as weather forecasting, land use mapping, agriculture and environment monitoring. Until now, all EOS images were obtained from foreign satellite systems. Realising on the strategic need of having its own capabilities, Malaysia has embarked into EOS development programmes since the early 1990s. Starting with TiungSAT-1, a micro-satellite carrying a small camera, then followed by RazakSAT, a small satellite carrying a 2.5 m panchromatic (PAN) medium-aperture-camera, the current satellite development programme, RazakSAT-2, designed to carry a 1.0 m high resolution PAN and 4.0 m multi-spectral camera, is a strategic initiative of the government in developing and accelerating the country’s capabilities in the area of satellite technologies and its applications. Would this effort continue until all needs of the remote sensing community are fulfilled by its own EOS? This paper will analyse the intention of the Malaysian government through its National Space Policy (NSP) and other related policy documents, and proposes some policy options on this. Key factors to be considered are the specific data needs of the EOS community, data availability and more subjective political motivations such as national pride.

Keywords: Earth observation satellite (EOS); remote sensing (RS) users; National Space Policy (NSP); RazakSAT satellite series; policy options for the government.

1. INTRODUCTION: EOS APPLICATIONS IN MALAYSIA

Earth observation satellite (EOS) is currently a major tool to monitor earth dynamics and increase human understanding of earth surface processes as well as atmospheric dynamics. The early applications of remote sensing (RS) sciences and applications in Malaysia were initially for meteorological applications using the National Oceanic and Atmospheric Administration’s (NOAA) Television Infrared Observation Satellite (TIROS) in the 1960s. RS applications for land resources and environmental studies started in the 1970s with the availability of images from the Landsat series of satellites. For an equatorial region such as Malaysia, the main limitations of optical images are continuous cloud cover over the region and severe raining seasons especially at the beginning and end of the year. In the 1990s, the use of radar EOS images mainly from the RADARSAT satellites managed to overcome some of these problems. Currently both optical and radar images are widely used, but the repeat capabilities of each satellite are still not sufficient for operational RS purposes (Mohamad et al., 2004).
For some time, satellite images from the Landsat and SPOT satellite series have been the most widely used EOS images for various land and marine applications. The SPOT satellites with better spatial resolution and stereo capability have enhanced applications in areas such as topographical mapping. Current QuickBird (0.6 m), WorldView-2 (0.5 m) and GeoEye-1 (0.5 m) sub-metre resolution images have enabled detailed mapping, such as utilities, to be carried out. Most of these applications are done post-processed.

For many operational RS applications, which are mostly decision making-related such as disaster-related monitoring and surveillance, real-time or near-real time data supply is needed, but this data is not sufficient. Apart from insufficiency in repeat imaging capabilities, these satellites are mostly polar-orbiting or sun synchronous orbiting (SSO), with longer revisit times, further restricting the use of EOS images for operational purposes. Other shortcomings of the current supply of EOS images include data availability, normally long period of delivery, and data suitability and price.

2. THE EOS PROGRAMME: THE CAPACITY BUILDING WAY

The demand of EOS images for various RS applications is ever increasing in both the public and commercial sectors, with dominance in the public sector. EOS images and RS applications have become an important administrative tool. Ironically, as highlighted earlier, until now, all EOS images have been obtained from foreign satellite systems.

Realising on the strategic need of having its own capabilities, Malaysia has embarked into EOS development programmes since the early 1990s. Starting with TiungSAT-1, a micro-satellite carrying a small camera, then followed by RazakSAT, a small satellite carrying a 2.5 m panchromatic (PAN) medium-aperture-camera (MAC), the current satellite development programme, RazakSAT-2, designed to carry a 1.0 m high resolution PAN and 4.0 m multi-spectral camera, is a strategic initiative of the government in developing and accelerating the country’s capabilities in the area of satellite technologies and its applications.

The question to ask here would be: (1) what is the direction of the country on EOS?

EOS is normally a government-led programme (ANGKASA, 2012), as part of a technology capability building effort, with the key objective of this initiative being to fulfill a part of the domestic RS user community’s requirements on specific spectral frequencies and spatial resolutions. It may also be mixed with more subjective, political motivations such as national pride.

There are debates on whether governments in developing countries should just rely on EOS images globally available, or consider the need to own and operate their own satellites. The general conclusion would be to adapt the earlier option, but there are subtle realities that challenge this conclusion. EOS data available from the international community can be shared with countries that do not own satellites, including from commercial providers that sell high resolution satellite imagery. However, the problem remains that developing country cannot always get the data that they need when they need it (Wood & Weigel, 2011). This may be because the data collected by other countries does not account for the technical requirements of a particular user in a developing country, such as spatial and temporal frequencies, spatial resolution, and geographic coverage. Furthermore, organisations from developing countries that wish to share international data may be obliged to establish bilateral agreements with each
data producer and keep these agreements up-to-date in order to ensure access (through licensing agreements), which is generally an expensive exercise. Meanwhile, high resolution optical data, which is particularly useful for projects in urban planning, is mainly available from commercial providers and could also be very expensive.

A long term solution for the country in fulfilling the needs of the local RS community is very much needed. In the absent of any official policy stand of the government, this could be difficult to answer. This paper will analyse the intention of the Malaysian government in this issue, through its National Space Policy (NSP) and other related policy documents, and proposes some policy options on this. Key factors to be considered are the specific data needs of the RS community, data availability and more subjective political motivations.

3. **THE EOS PROGRAMME ROADMAP: THE BASIS**

3.1 The Satellite Development Programme

Malaysia has ventured into satellite making since mid-1990 through the purchase of its first two communications satellites, MEASAT-1 and MEASAT-2, from Boeing Ltd. The MEASAT satellites are owned by Binariang Sdn. Bhd. (now Measat Satellite System Sdn. Bhd.), a private entity providing satellite communications-based services in the country as well as globally. Although it is a commercial purchase, some local engineers were sent to Boeing during the development period, to acquire some level of knowledge and know-how in satellite making.

A real transfer-of-technology (ToT) programme in satellite technology was done with Surrey Satellite Technology Ltd. (SSTL), United Kingdom in the mid-1990s. Ten engineers from Malaysia were attached with SSTL throughout the development of TiungSAT-1, which was launched in 2000 and operated for more than three years. This project was undertaken by the Space Science Studies Division (BAKSA), a division then under the Ministry of Science, Technology and Environment (MOSTE). Subsequently, a government-linked company (GLC), Astronautic Technology Sdn. Bhd. (ATSB) was formed as a special vehicle to continue undertaking the task of capacity building in satellite technology for the country.

The National Space Agency (ANGKASA) (incorporating BAKSA) was formed in 2003 to spearhead the development of the space sector for the country. Utilising a grant from ANGKASA, ATSB developed RazakSAT (2004-2009), a research & development (R&D) remote sensing satellite, jointly with a South Korean company, Satrec Initiative (SatRecI). RazakSAT, carrying a MAC was successfully developed, launched, going through its Launch and Early Operation Phase (LEOP), and operated for about eight months. Unfortunately it ceased operation in mid-2010 due to some components malfunctioning, believed to have been caused by excessive exposure to solar radiation particles in the region of the South Atlantic Anomaly. During the course of the development and operations of RazakSAT, about 100 engineers and scientists were involved, plus expertise in related areas such as satellite operations and image processing.

The current EOS development programme, the RazakSAT-2 satellite, is a continuation of the country’s strategic capacity building initiatives in satellite technologies. A development project under ANGKASA (2013-2015), with ATSB as the main contractor, the intended outcome of this project is not only an operational high resolution remote sensing satellite, but also to achieve the total spectrum of the capacity building aspects in satellite technologies for the country.
3.2 The National Space Policy (NSP)

Although work on the development of the NSP started way back in 2005, until now (2014), it has not been officially endorsed. It is supposedly the strategic document that charts the way forward and provides the framework of the development of the space sector for the country (ANGKASA, 2012).

The document envisions on building the nation’s capabilities to embrace space as a strategic sector for the nation’s wellbeing towards achieving Vision 2020 and beyond. This could be achieved by developing the country’s potential in the space sector to support the development of the new economy, and strengthening national security. The listed objectives of the policy are:

1. To build up space infrastructures and industries for economic benefit and safeguarding the nation’s sovereignty.
2. To empower the civil society in enriching their quality of life through information from innovative application of space technologies.
3. To capitalise/harness on space as the frontier for new knowledge generation towards contributing to scientific and technological advancement.
4. To ensure critical mass of talent in space related sectors to support the realisation of the NSP.

3.3 The National EOS Programme

The draft NSP outlined the direction of the satellite development programme for the country until 2020. This is under Programme 3: Accelerating Space Technology and Infrastructure Development, with the related plan of action in the National Satellite Development Programme that includes the EOS Programme, National Communications Satellite Programme and Global Navigation Satellite System (GNSS) Programme (Figure 1).

![Figure 1: Components of the National Satellite Development Programme.](image-url)
Under the EOS programme, it is outlined that:

‘Malaysia’s EO satellite series (RazakSAT) should be continued because it will play a very important role in resources investigation and the monitoring of environment disasters. EO satellite data can be applied to numerous fields such as agriculture, forestry, water resources, land use, cartography, mineral exploration, and ocean investigations. The technology and expertise acquired in developing the EO satellite can then be applied to the development of the more sophisticated communications satellite’.

4. THE EOS CAPACITY BUILDING PROGRAMME: TO BUILD OR TO ACQUIRE?

The next question to ask would be: (2) would this effort of capacity building continue until all needs of the local RS community are fulfilled by our own EOS?

The ability of a nation to drive innovation and economic progress depends on its science and technology capacity. This was the thought process for the development of the National Science and Technology Policy (NSTP), the second NSTP (NSTP II) and the National Action Plan for Industrial Technology Development (Fadzilah and Krishna, 2007). This ability shall include all factors including the manpower and personnel to conduct research, and carry out technological development, infrastructure, investment, institutional arrangement and regulatory framework.

Satellite technology development has long been recognized worldwide as an indicator of science and technology capacity. It has been the domain of technologically advanced countries and regions such as the United States, Europe, Japan and, recently, China. However, an increasing number of developing countries, Malaysia included, have started to enter this strategic sector especially through joint development of small satellites. It is known that the engineering knowledge and work experience gained in these satellite programmes is often directly transferable to other technology fields.

Several issues of pertinence that could lead to certain policy options are highlighted as follows:

i. Digital Earth and EOS

As the country moves towards being a fully developed nation by 2020, digital-economy adoption requires the setting up of digital infrastructures such as the Digital Earth (DE). DE, or technically known as the Spatial Data Infrastructure (SDI), would enable the full capitalisation of geospatial data among users and data providers in the country (Abu Hanifah & Majeed, 2007).

An EOS, as the provider of the basic data to an SDI in the form of various satellite images, would be an important component in the realisation and maintenance of the country’s SDI. China, for example, has placed great importance on the development of EOS (Huadong, 2012). Four satellite series in China, which are resource, environment, meteorological and ocean satellites, have been developed within the past few decades. They have also planned to have more high-resolution remote sensing satellites for building their next generation DE.
ii. Building the EOS programme: Whose job is it?

The development and operation of an EOS system requires a significant commitment. Without a clear return on the investment for an expensive venture as such, it is the government financial mechanism that would be the best one to support such implementation. The private sector, on the other hand, is expected only to be involved in the downstream applications of it, further enhancing the justification of such a programme. In fact, most EOS programme implementations are not-for-profit making ventures, but more of a national need, i.e., more on the justification of strategic needs, rather than economy. Again, China has clearly shown that it is the government’s job to do it (Huadong, 2012).

iii. Fulfilling the domestic RS community’s needs and sustaining of the EOS programme

As is the case elsewhere, the local RS community certainly has a wide range of EOS image needs. A recently conducted user requirement survey (ARSM, 2012) indicated that slightly more than 50% of the demand is in utilities, infrastructures and engineering works. This clearly indicates that images of higher resolution (1 m or better) are much needed by the local RS users. On the signal side, optical images are still the preferred choice for such applications, for ease of use and cost. Based on this need, optical payload was chosen for the current government EOS development programme, the RazakSAT satellite series. As such, it is important for the EOS programme to be continued and sustained by the government. The survey has also indicated that the next EOS programme for the country should be satellites carrying radar payloads.

iv. The operational needs of EOS

It has been mentioned earlier that the business of getting data from foreign service providers are faced with issues such as data unavailability, or the data available does not account for the technical requirements. Another major shortcoming of current foreign EOS services is the ability to provide the required images at the required time for operational purposes. This is understood simply due to the nature of EOS operational parameters. With most EOS flying at SSO, the repeat visit could well be more than a week. For operational purposes, such as monitoring a forest fire, this gap in imaging opportunity is just too long. Even with multiple EOS available, this gap is still a major concern. In addition to that, for most operational applications, where optical images are preferred, continuous cloud cover would add on to the problem.

v. To sit on the upper bench: The ability to contribute

EOS images have been integrated into disaster-management initiatives such as Sentinel Asia and United Nations platform for Space-Based Information for Disaster Management and Emergency Response (UN-SPIDER), where Malaysia is a member. These initiatives work on mutual cooperation, with members of the consortia contributing in assisting other members stricken by disasters through data obtained via their infrastructures, for example, supplying images from their EOS. Within such an arrangement, the ability to contribute would indirectly give the member-country the credits. The more significant the contributions are, the more credit it will get. It is time for Malaysia, a leading member country of ASEAN, to have our own EOS – else the country is merely a recipient of these initiatives or simply put, the end users!
5. **THE OPTIONS**

In order to ensure full capitalisation of the sector, it seems that the way forward is to build the country’s capabilities in EOS, mainly in small satellite missions. So far, this seems to be the current strategy of the Malaysian government. This strategy is not aimed to make the country independent from using foreign satellite images (which even space faring nations are not doing), but rather on having the capabilities to develop, launch and operate critical and much needed selected EOS missions. In implementing this strategy, we believe both options of acquiring some and building some should be taken. Furthermore, in addition to Programme 3, another important programme in the draft NSP is under Programme 1: Exploring Space for New Knowledge & Scientific Discovery, where it is indicated that a specific orbital designation is to be favoured, i.e., on enhancing the Near Equatorial Orbit (NEqO).

With these, we would like to propose options for the development of the EOS programme in the country, as follows:

**i. To continue with the EOS capacity development programme**

Currently we have the capability and capacity to design and develop (assemble, integrate and test) small (<1 tonne) satellite buses and related sub-systems. We are also capable to launch (utilising launch service providers) and operate such systems. For RazakSAT, the optical payload, a MAC, was jointly developed with SatRecI. As for RazakSAT-2, it is still to be jointly developed with a foreign technology partner. We need to have R&D on payload development, either optical, radar, hyperspectral or others. This would then complete the capacity building process.

**ii. To continue with the RazakSAT satellite series**

Optical payload would still be the preferred payload for most applications. For this, the RazakSAT satellite series (optical payloads) should be continued. Once the RS community has built up applications using the RazakSAT-2 imageries, the dependency on the continuous supply of the images will be established, and then, it will be the responsibility of the government to ensure the continuity of such services. The planned spatial resolution of 1.0 m PAN and 4.0 m multi-spectral of RazakSAT-2 would seem to satisfy the majority of domestic RS users. Future camera resolutions should be determined prior to new mission developments.

**iii. To have a radar satellite development programme**

Being at the equatorial region, having continuous cloud cover is a challenge. A radar satellite would greatly enhance the imaging needs of the local RS community. After limiting the satellite mass to be less than 1 tonne, which we already have capability of, the development would then be focused to the payload of the mission. That would probably be a mini-version of a radar. This could be targeted as the next development after the RazakSAT-2 programme.

**iv. To continue pursuing the utilisation of the NEqO**

Malaysia has pioneered the NEqO with RazakSAT. The draft NSP has also recommended the pursuance on the capitalisation of NEqO. NEqO simply gives the opportunity in high imaging
repeatability for Malaysia, hence giving a huge advantage for operational RS applications such as forest fire monitoring. With a repeat of about 14 times vicinity imaging per day (including night time of course!), this could really enhance the monitoring operations.

The coming RazakSAT-2 satellite will, unfortunately, fly the SSO. This decision was temporarily taken in consideration of several reasons, amongst them perhaps being:

- The need to optimise the return of investment (ROI) of RazakSAT-2. With SSO, there is the capability to image the entire globe, hence increasing the potential of economic earning to the country.
- The local RS community is accustomed to commercial image processing software which is mainly based on SSO images. Hence, non-SSO images (such as NEqO) pose difficulties for them.
- Local researchers are still not ready to capitalise NEqO images that have variation in sun-angle, shadows and sun-illuminations.

These are but challenges that have to be overcome by local RS experts and users before the next EOS missions can be realised.

6. CONCLUSION

The country has made the right policy in developing its local capability in the EOS programme. It does not aim to make the country independent from using foreign satellite images, but rather on having the capability to develop, launch and operate critical and much needed selected EOS missions. It is still the role of the government to ensure the successful implementation of this strategic initiative. Full capability is almost achieved except for some areas such as payload. With the acceptance and implementation of the NSP, this could well be achieved by 2020.

REFERENCES


DEVELOPMENT OF AN EFFECTIVE ROAD MANAGEMENT SYSTEM USING WEB-GIS SOFTWARE

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ABSTRACT

Recently, there has been rapid development of road transportation networks. This situation arises due to the number of vehicles on the road that keeps increasing year by year. Thus, this will increase the possibility of dangerous situations to road users if the roads are not being maintained appropriately. Therefore, in order to keep the roads in safe condition, road management activities should be improved. A complete system for road management has been applied in developed countries for the past decades. However, the usage of application programming interface (API) from commercial geographical information systems (GIS) software has limitations in making modifications in terms of interactivity of the system. In this paper, open source software (OSS) is proposed as a way to assist in reducing the costs in developing a web-GIS road management system. The system can be used by administrators of road networks to update the road information. At the same time, it can be used by road users to view information regarding road-related incidents.

Keywords: Road management system; web-GIS; open source software (OSS); three tier architecture; OpenLayers.

1. INTRODUCTION

Recently, there has been rapid development of road transportation networks throughout the world due to increased human population and economic activities. The increase of vehicles on roads has demanded the commitment to improve the current road transportation systems to help the authorities in monitoring and managing road infrastructures effectively. However, in order to keep the road infrastructures in safe condition, a comprehensive monitoring and managing system should be developed. By providing a comprehensive road management system, the occurrence of road accidents also can be minimised (Ma, 2008). Several countries have developed road management systems for the past few decades for their countries. However, the existing systems still can be improved for future work and wider scope (Kubota et al., 2011).

The application of geographical information systems (GIS) for road management systems has been used in developed countries (Yusoff et al., 2014). It is an effective system to monitor all of the activities that occur on the roads and store the records for future development. Furthermore, this system can be as a decision support system (DSS) for road development and construction in the future. To make this system easy to access, it is developed in the form of a web-GIS. Web-GIS is an internet-based platform that provides client-side applications using worldwide web (WWW) protocols running on the internet, which can embed geographic information data as well as non-geographic data (Feng & Quanwen, 2010; Xie, 2010). It is a new type of GIS has arisen from the rapid development of internet (Xinkai et al., 2009).

In previous studies, web-GIS based management systems have proven to be able to manage the road network systems effectively. Feng & Quanwen (2010) implemented a web-GIS system for a highway
pavement management system by integrating spatial and attribute databases in the system. Meanwhile, Kubota et al. (2011) proposed a road maintenance information portal system to facilitate the sharing and retrieval of information among projects. Generally, API is used for interaction between components in the system. However, the usage of application programming interface (API) from commercial GIS software has limitations in making modifications in terms of interactivity of the system (Steiniger & Hunter, 2012). Furthermore, the usage of commercial software requires product licenses, which need to be renewed every year. Consequently, the developer needs to spend significant amount of money to maintain the software.

Therefore, the objective of this study is to propose an effective road management system to improve the current system. Open source software (OSS) is used in developing the web-GIS system in order to minimise the development costs. By implementing this system, it provides a comprehensive system that can monitor and manage road conditions, which can also able to be accessed by users through the internet.

2. METHODOLOGY

The flowchart of this study was designed to guide the authors to achieve the objective. Five methodological steps were designed, as shown in Figure 1. Requirement analysis is a process that is usually taken to identify problems that exist in the study area. This step involves various procedures and materials. A preliminary study was conducted to identify the latest and previous systems that are able to support spatial data for road management systems. Interview sessions were also conducted with related government agencies in Malaysia, such as the Malaysian Highway Authority (Lembaga Lebuhraya Malaysia, LLM), and experts in road management systems. Based on this, the deficiencies of the current system were identified.

![Figure 1: Methodology for the development process of the system.](image-url)
The information gathered was utilised to develop a comprehensive web-GIS system that is able to overcome the deficiencies in the current system. The standard procedure in system development was applied in this study, which started with system design, software and hardware survey, database design, and programming code. Then, the system was tested to identify the reliability and robustness in serving the functions for administrators and distributing information to users.

Hardware and software selection are vital components of the GIS field. High performance of hardware is needed to support the speed of data and processing for the web. The next component that is essential in web development is the database platform, which is used to store all information in one location for manipulating, processing and presenting to users through a web browser. The database design takes into account the overall database structure, including the elements of the database. The elements of the database consist of entities, attributes, and the relationship between the entities and attributes. System development is the phase to make the configuration of software and data entry and editing of the attributes in the web-GIS system. After the system is completely developed, it needs to be tested or validated in terms of quality and competency in providing the functions to the users.

2.1 System Design Architecture

Web-GIS has the capability to input, process and visualise results on-screen using an internet platform. System design is the main procedure in web development as it shows the overall components in the system. The development of the web-GIS system has three vital components to make it run efficiently, as shown in Figure 2.

![Figure 2: The architecture of the web-GIS system.](image)

2.2 Client Tier Architecture

The client tier consists of a web browser to display information to the users. This tier is the interface to receive user requests for processing. Various web browsers can support the client tier such as Internet Explorer, Mozilla Firefox and Google Chrome. The web browser allows users to input their request. In this study, the interface was developed using the hypertext markup language (HTML) as the main programming script of the interface. The contents of the web page were written in HTML form before publishing on the web browser. At the same time, the JavaScript programming language was embedded into the HTML scripts to generate interactive and dynamic visualisations.

The client tier is the main page of the system that deals with the users. The graphical user interface (GUI) receives user requests through the web browser. Then, the requests will be transferred to the database tier for processing. The data needed will be retrieved from the central database in the
database tier. Subsequently, the result will be transferred again through web tier and visualised on the client tier for user.

2.3 Middle Tier Architecture

The middle tier is the most important tier of the whole system. The function in this tier is to control the whole process of the system. After the client tier receives requests from the user, the results will be sent back to user via middleware. It serves as the intermediate medium between the client and database tiers. The connection requires hypertext transfer protocol (HTTP) and structured query language (SQL) that can translate between them.

The OpenLayers framework was attached in this tier for map visualisation. OpenLayers provides functions for displaying maps in web browsers using a JavaScript library. It is the foundation of all web mapping frameworks, such as Google Maps, OpenStreetMap, Google Satellite, Yahoo Maps, and Bing Maps (Perez, 2012). This research used three web mapping applications, which are Google Maps, Google Satellite, and OpenStreetMap, to provide a variety of interface displays, as shown in Figure 3.

Figure 3: The OpenLayers framework for web mapping rendering.

2.4 Database Tier Architecture

The database tier, also known as the server tier, is the database management system (DBMS) of the system, which stores and retrieves information. The PostgreSQL/PostGIS database was placed in the database tier to manage and provide data when the processing is run. Hypertext preprocessor (PHP) was used in the database tier as server-side scripting language to communicate with the client tier. The PHP code was embedded in the HTML code. When client tier invokes the HTML page, the Web server executes the scripts, which in turn access the data from the PostgreSQL/PostGIS database. The Web server then organises the data into the HTML page and sends it back to the web browser. Thus, users can view road information and shortest path route that is retrieved from the database on the web page.
2.5 OSS and Usage

The development of OSS for GIS usage has been implemented in the last ten years (Steiniger & Hunter, 2012). OSS is a free license software that has capabilities similar to license software, but allows for modification for any purpose (Moreno-Sanchez et al., 2007). Nowadays, it has become popular and reliable for current systems. For GIS usage, the software must have capability for creating, managing, analysing and visualising geographic data (Steiniger & Hunter, 2012). To minimise the costs, this study utilised OSS for web development and is attached with free database system software as well. Hence, this study can be categorised as a low cost project and can be implemented in the real situation to replace the current system.

One of the important components in web development is the web server. This component enables the information from the database to be accessed using the WWW protocol. The Apache web server, also known as the Apache HTTP server, is a well-known open source web server platform. Apache is a high performance web server with full feature functionalities. For the database platform, this study applied the concept of integration of PostgreSQL and PostGIS as the database management system, which transfers data through the internet protocol. This database was used because it is one of the most advanced open source databases available (Anderson & Moreno-Sanchez, 2003).

2.6 Development of the Web-GIS System

This system was developed using a workstation with the Windows 7 operating system. The hardware specification of the server was a 2.4GHz Intel® Core™ i5 processor with random access memory (RAM) of 4GB. The server runs the WampServer web development platform to retrieve data from the PostgreSQL database using the PHP language. The database used was PostgreSQL 9.1 with the PostGIS 1.5 spatial extension to support geographic data.

The developed system can be used for administrative usage to input all information of roadwork activities that occur on the road. Moreover, it can be a control station to monitor construction works on the roads. Symbols will appear on the map included to indicate the progress status of the roadwork. At the same time, it can be used by the road users as well to view information regarding road activities that happen on the road.

The selection of software should be done in proper way because different software have different advantages and disadvantages. The selected software must be evaluated in terms of functionality so that it will not affect the system when it is running. In order to make this system cost-effective, free software was used. PHP 5.4 was used as the server-side scripting language and PostgreSQL 9.2 as the database platform. JavaScript was used to write the coding for the client-site to produce interactive and user-friendly web pages. Then, a web browser, such as Mozilla or Internet Explorer, will function as the user input and display the output after processing.

3. DISCUSSION

The GUI was developed to integrate all the functions proposed in the developed web-GIS road management system. The interface was developed using HTML and combined with the JavaScript code to make it more dynamic. In the main interface, there are five menus on the header of the interface. All the available functions are shown on the interface for user consideration. Figure 4 shows the main interface for the web-GIS system.

The five menus that were created on the main interface were Home, Admin, User, Partners, and Contact Us. Each menu has specific functions to serve users when interacting with the system. The Home menu provides the homepage of the web-GIS interface. When users click on this tab, it will return the users to the homepage. The second menu is Admin, which was designed for administrative usage. In order to keep the data precise, only registered users can edit and update information in the
database. This is because some current systems allow public users to input the information freely. This situation can reduce the authorisation of data in the database. Therefore, to make sure all the inserted data was free from vandalism, the Admin function was enabled in this system.

Figure 4: The main interface of the web-GIS road management system.

The next menu is the User menu, which consists of the main content of the web-GIS system, showing the three base maps using the OpenLayers framework. Users can choose which base map they prefer by selecting on the right menu. This function was created in this system to enhance the visualisation of the base map. The second function of the User menu is generating shortest path analysis (Figure 5). Users need to input their origin and destination nodes in the provided columns. If they need the specific time for travelling, they can insert the date and time in the provided columns. The reason this system chooses to use node value as the input unit instead of street name is because it can detect the exact location of the source and target on the map, which increases the accuracy of the system. However, sometimes it is difficult for users to get the correct location based on the node value.

Partner is the fourth menu in the interface of the system. Unlike the other tabs, this tab uses a dropdown menu that lists the potential partners from government and private departments that are related to road management in Malaysia, such as LLM, Public Works Department (Jabatan Kerja Raya, JKR) and PLUS. This menu was created in this system to integrate information within different departments. The last menu of this system is Contact Us, which is used to provide information about the person who users can contact regarding to the web-GIS system.

4. CONCLUSION

In this paper, a comprehensive system for road management system was developed using OSS. Free software was used because it is becoming popular nowadays. Web-GIS become the core part of the system since it can support road data which consists of spatial and non-spatial data. The development of this system involves two parts, which are system design and development. This system will give benefits to road administrators to gather information in a single database and can work as a DSS for road maintenance. At the same time, it can provide visualisation for public users to plan their journey. By accessing this system, administrators from authority departments can update information in the database easily. Only registered users are allowed to update the information in the database in order to
maintain the authenticity of information. The road users can visualise the base maps in the interface, and interact with the system using the options for flying through, pan, slide and viewing road condition with the roads information screen. Shortest path analysis is also provided in the system to enhance the capability of the system. For future work and improvement of the web-GIS road management system, we suggest that the data be collected from the related agencies to insert into the database. This will allow the database to become more updated, with the quality of data certified. Other features such as photos and videos can be uploaded into the database to improve map visualisations.

![Image of web-GIS road management system interface](image)

**Figure 5: Shortest path between two points.**

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**REFERENCES**


INTEGRATION OF GEOSPATIAL MULTI-MODE TRANSPORTATION SYSTEMS IN KUALA LUMPUR

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ABSTRACT
Public transportations serve people with mobility and accessibility to workplaces, health facilities, community resources and recreational areas across the country. Development in the application of geographical information systems (GIS) to transportation problems represents one of the most important areas of GIS technology today. In order to demonstrate the importance of GIS network analysis, this paper highlights the determination of the optimal path between two or more destinations based on multi-mode concepts. The abstract connector is introduced in this research as an approach to integrate urban public transportation systems in Kuala Lumpur, Malaysia including facilities such as Light Rapid Transit (LRT), Keretapi Tanah Melayu (KTM) Komuter, Express Rail Link (ERL), KL Monorail, road driving as well as pedestrian modes into a single intelligent data model. To assist the analysis, ArcGIS’ Network Analyst functions are used, whereby the final output includes the total distance, total travelled time, directional maps produced to find the quickest and shortest paths, and closest facilities based on either time or distance impedance for multi-mode route analysis.

Keywords: Multi-mode transportation; network analysis; optimal path; abstract connector; closest facility.

1. INTRODUCTION
An efficient transportation network can stimulate economic transformation, physical development, and improve mobility. Urban areas are populated by over half of the world’s population and are anticipated to witness most of the population growth in the next forty years (Spickermann et al., 2013). With an increasing population, the demand for transportation will also increase (Farahani et al., 2013). In certain locations such as urban areas, human mobility usually happens over a multi-mode transportation network. People tend to use more than one mode of transportation to arrive at a particular destination due to many reasons. Accordingly, when analysing transportation systems people should not simply consider each mode of transport separately but rather, should look at it as a multi-mode transportation system with relationships and dynamics between components. Moreover, each mode of transport has its weaknesses and strengths, and use a combination of modes can potentially cancel out their negatives, offering an advanced platform for more flexible, efficient, sustainable and reliable transportation (Mahrous, 2012).

There are works done beyond the urban territories such as reported by Frederic et al., (2008), who highlighted the development of databases regarding territories all around the world where multi-mode transport systems are being established. These databases are not only to be used for integrated mobility information services, but also for new analysis to improve global multi-mode transportation over a territory. In fact, transportation planners and decision-makers are increasingly considering multi-mode transportation strategies to support sustainable transportation associated with urban development (Krygsman, 2004; Matthew, 2013). This is of a particular importance when more people are getting mobile with the availability of new public transportation options that connects the routes.
In Malaysia, mainly in Kuala Lumpur, the network has become more complex and complicated. Common transportation features that can be observed include multi-layer highways and major roads with many intersections. In fact, urban public transportations, such as Light Rapid Transit (LRT), Keretapi Tanah Melayu (KTM) Komuter, Express Rail Link (ERL) and KL Monorail, exist to boost economic development in the city. Currently, public transportations that operate within the Klang Valley area is managed by various separate companies. For instance, RapidKL operates on LRT, which consists of two lines, namely the Kelana Jaya and Ampang lines. RapidKL is also in charge of the KL Monorail. Kereta pi Tanah Melayu Berhad (KTMB) on the other hand operates on KTM Komuter, while Express Rail Link Sdn Bhd operates on ERL. However, none of these network lines lie on the same platform as each other. For example KL Monorail line is not connected physically with any other line.

Determination of an optimal path within a highly complex transportation network is not an easy task, especially for those who are unfamiliar with the local transportation system. Users might get confused when travelling from one place to another. Integration of multi-mode transportation systems would not only ease travellers’ transfer from origin to destination, but also make their journey a more enjoyable and less stressful experience (dell’ Olio et al., 2011). A complicated network of route systems requires critical analysis which can only be realised with the implementation of geographical information systems (GIS) to improve the movement of people. Moreover, they are not integrated, i.e., they exist as separated systems.

Even though some of well-known route planning systems (Figure 1) are making efforts to integrate more transportation modes, it is unfortunately performed completely separate for each mode, i.e. one mode at a time (Liu, 2010). In fact, several problems have been identified for route determination of the Kuala Lumpur area using Google Maps, such as lack of or missing pedestrian paths. The combination of modes is not logical, and the pinpoints of origin-destination are not snapped precisely. This can lead to misunderstanding of information generated and might get users into troublesome situations.

![Figure 1: Separation of transportation modes in: (a) Google Maps (b) Bing Maps (c) MapQuest.](image)

To date, there is no such work which involves the modelling and integrating of urban public transportation in Kuala Lumpur. Hence, the main aim of this study is to develop an intelligent and integrated data model of route network systems within a GIS environment using the abstract
connector. To assist the analysis, ArcGIS’s Network Analyst functions are used, whereby the final output includes the total distance, total travelled time, directional maps produced to find the quickest and shortest paths, and closest facilities based on either time or distance impedance for multi-mode route analysis.

2. MODELLING A MULTI-MODE TRANSPORTATION FRAMEWORK

The metropolitan city of Kuala Lumpur, Malaysia has been selected as the study area. This area contains most of the transit systems (LRT, Monorail, ERL, KTM Komuter) in Malaysia. This Federal Territory covers an area of 243 km² (Mohamad, 2005). Under the 1984 Kuala Lumpur Structure Plan, the city centre was designed as the principal core to provide specialised metropolitan services, national and international commercial and business activities, central government activities, and much more.

2.1 Designing an Abstract Connector System

One of the crucial parts in designing a geospatial multi-mode transportation network is the integration of available networks (road, rails and pedestrian) into a single layer. In this research, the abstract connector (Figure 2) is adopted, which acts as a ‘bridge’ to connect between different modes of transportation. It also reflects the transfer process within the movement of people. The solid lines in Figure 2 represent physical networks while the dashed lines illustrate the abstract connector links. The physical network edges contain required attributes such as travelled time, speed limit, length, etc. The physical nodes (shown with green circles) represent locations associated with X and Y coordinates as required attributes.

![Figure 2: Adopting an abstract connector system in a multi-mode transport network.](image)

In the Kuala Lumpur area, transit stations are accessible using the pedestrian network. The pedestrian network plays a key role in mode transfer. Thus, abstract connectors are properly situated at the intercept point between the transfer links and walkways that lead to the transit stations. It is to be noted that there are two types of transfers; one is transfer within the same mode (e.g., transfer from the KTM Komuter Sentul -Pelabuhan Klang Line to the Seremban -Rawang Line), the other is between different modes (e.g., transfer from KL Sentral’s LRT to the Tun Sambathan Monorail).
2.2 Building Network Dataset

Building a network dataset is a compulsory procedure to ensure that the data is ready for network analysis to take place. There are five steps required in order to create a network dataset which are: (i) Naming the network dataset and choosing source feature classes; (ii) Assigning connectivity policy and connecting groups; (iii) Setting elevation policy; (iv) Specifying the attributes for the network dataset; and (v) Configuring directions.

For the travel time calculation, the formula as shown in Equation 1 is used. It is very important to ensure that the units used are correct and comply with the formula. The distance refers to the road length in unit m, while the speed limit is converted from km/h into m/min.

\[
\text{Travel time (min)} = \frac{\text{Distance (m)}}{(\text{Speed limit} \times \frac{1000}{60})} \tag{1}
\]

A measure of the amount of resistance, or cost, required to traverse a path in a network is known as impedance. If the impedance is the distance (m), the optimal route is the shortest route. On the other hand, if the time (minutes) is chosen as impedance, the optimal route is the quickest route. Figure 3 shows how a user can define the suitable impedance for a journey.

![Layer Properties](image)

**Figure 3: The choice of impedance.**

2.3 Assumptions of the Analysis

The analysis is based on two assumptions: (a) Travel time is calculated on the condition that there is no traffic jam in the streets; and (b) Travel speed is considered as the maximum speed limit, which is assigned based on the Malaysia’s road classes (Table 1).

<table>
<thead>
<tr>
<th>Road Class</th>
<th>Speed (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highway</td>
<td>110</td>
</tr>
<tr>
<td>Federal</td>
<td>90</td>
</tr>
<tr>
<td>State</td>
<td>90</td>
</tr>
</tbody>
</table>

2.4 Geodatabase Design and Development

Geodatabase design is the process of producing a detailed data model of the database to meet end user requirements. The entity relationship model (ERM) is most commonly used during conceptual design. The resulting entity relationship diagrams (ERDs) provide a data-centric and structural view of the database. A new option is to use a unified modelling language (UML) which contains class diagrams
that also incorporate structural views of the database. Figure 4 depicts the conceptual design adopted for the data model.

For this research, the major (required) feature classes (map layers) are road networks, and transit stations and lines (LRT, ERL, KTM Komuter, KL Monorail), with the correct network topology. The supporting feature classes include points of interests (POIs), transfer points and connecting interchange stations. As accuracy is not an issue for this research, the point and line data are extracted from Google Earth’s images, Google Maps, websites and Garmin BaseCamp 4.2.5 map data. Figure 5 shows the geodatabase model developed for this application based on the Malaysian Standard Geographic Information / Geomatic Feature and Attribute Codes (MS1759). The geodatabase is divided into three main feature datasets, which are built environment, demarcation and transportation. Therefore, it enables the geodatabase to more accurately model the network dataset relationships and maintain data integrity, resulting in a more reliable output.

![Figure 4: Conceptual design of the UML database.](image)

![Figure 5: The developed geodatabase model.](image)

### 3. APPLICATION TESTING

The framework presented in the previous section is used to model and analyse the public transportation systems in Kuala Lumpur’s metropolitan area. The user can visually select the origin-destination without having to manually input information regarding the facilities on the networks. Moreover, with the database associated, it will assist users to have a better interpretation of the network characteristics and minimise the potential for errors being generated in the network data files. The well-known Dijkstra’s algorithm embedded within the Network Analyst extension makes it possible to perform analyses such as optimal path and closest-facility determination.
3.1 Route Analysis in Multi-mode Transportation Network

In the real world, commuters and travellers frequently use several modes of transportation, such as walking, driving, and taking the trains. Figure 6 displays the transit systems available in Kuala Lumpur, including the LRT, KL Monorail, KTM Komuter, ERL, roads (driving) and footpaths (walking). For the LRT, it comprises of three lines; the Ampang, Kelana Jaya and Sri Petaling lines. Likewise, the KTM Komuter consists of two lines, which are the Sentul -Pelabuhan Klang and Seremban -Rawang lines.

In order to demonstrate a multi-model route analysis, the starting point or source is set to the Chowkit Monorail Station and the destination is the KL Sentral KLIA Transit ERL station. The bold pink colour line in Figure 6 highlights the best route to travel from the source to the destination. Meanwhile, Figure 7 shows the direction, total time and total distance for multi-mode transportation. In this scenario, the individual travelling uses five modes of transportation; KL Monorail, LRT, KTM Komuter, walking and ERL.
Figure 7: The directions, total time and total distance for multi-mode transportation.

It should be noted that the definition of connecting stations and interchange stations adopted for this application is as follows:

- **Connecting station**: A station that connects two different train modes. For example, the Putra station connects the LRT and KTM Komuter.

- **Interchange station**: An interchange between the stations that requires an individual to exit the station and then proceed to cross a footbridge that crosses a major roadway. For example, the Titiwangsa station is a rapid transit interchange station that allows for transfers between the LRT Ampang and Sri Petaling lines, and KL Monorail.
3.2 Closest Facility Analysis

The closest facility is a type of network analysis for finding the closest locations (facilities) from sites (incidents), based on the impedance chosen. For instance, finding transit stations near a current location. The users can specify a cutoff threshold beyond which the algorithm will not search for a facility. Figure 8 shows the results of finding the closest transit stations from a particular location (denoted as “A”) using the pedestrian mode. The green line is the monorail network whereas the blue and orange lines represent the LRT networks for the Sri Petaling and Ampang lines respectively. The network analysis function is executed, with the output showing that there are three nearby transit stations; the Titiwangsa Monorail, Titiwangsa Star LRT and Chowkit Monorail stations. The yellow line shows the directions to these stations. As depicted in Figure 9, the closest transit station is the Chowkit Monorail station, which is about 8 min from the current position. The results do not only give information about total distance and total time, but also the direction and map to the location.

![Figure 8: Closest facility analysis.](image)

![Figure 9: Least time, distance and direction of the closest facilities.](image)
4. CONCLUSION

Throughout this study, all of the urban transportation systems (LRT, Monorail, KTM Komuter, ERL, driving and walking) in Kuala Lumpur were successfully integrated into a single database model by adopting an abstract connector approach. This is to support the real needs of people when moving from one place to another in a situation that has many modes of transport available. All of these facilities were modelled in such a way that they are interconnected and an individual can travel from the start point to the end point. With a proper design of the database, users can freely choose the mode of transportation by either selecting single or multi-mode. This data model supports the display of the information regarding the total time, total distance, directions and a map to the selected destination. It is particularly useful to assist travellers in planning their journeys. This type of analysis can be used to find not only the shortest or quickest routes but also for other network applications such as modelling hydrologic flow, traffic flow and service areas. Consequently, using GIS, complicated networks of routes can be visualised and worked out in a very precise manner.

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ABSTRACT

In the Greater Mekong Sub-region (GMS), economic liberalization and deregulation facilitated by the GMS Regional Economic Corporation Program (GMS-ECP) has triggered urbanization in the region. However, the urbanization rate and its linkage to socio-economic activities are ambiguous. The objectives of this paper are to: (a) determine the changes in urban areas in Savannakhet, Laos from 1972 to 2013 using remote sensing imageries; and (b) analyze the relationships between urbanization rate and socio-economic activities. The study employed supervised classification and human visual interpretation to determine the urbanization rate from Landsat Multispectral Scanner (MSS) and Enhanced Thematic Mapper Plus (ETM+) imageries. Regression analysis was used to analyze the correlation between the urbanization rate and socio-economic variables. The results show that the urban areas increased significantly from 1972 to 2013. Socio-economic variables, such as school enrolment, labor force, mortality rate, water sources and sanitation facilities, were highly correlated with the urbanization rate during the period. The study concluded that identifying the highly correlated socio-economic variables with urbanization rate will enable us to conduct further urbanization simulation, which will help in designing policies for sustainable development.

Keywords: Remote sensing; supervised classification and human visual interpretation; urbanization rate; socio-economic variables; regression analysis.

1. INTRODUCTION

The Asian Development Bank (ADB) initiated the Economic Corporation Program (ECP) in the Greater Mekong Sub-region (GMS) in 1992, known as the GMS-ECP. It was started to promote mutual economic and social development by strengthening corporation among the GMS basin countries, which are Cambodia, Lao People’s Democratic Republic (Laos), Myanmar, Thailand, Vietnam and Yunnan Province in the People’s Republic of China (PRC). It facilitated market-liberal policies which provide excellent opportunities to develop the sectors of transportation, telecommunications, energy, human resources, environment, trade, investment, tourism and agriculture in the region.

The impact of the GMS-ECP, for example in the case of Laos, can be indicated by the amount of investment, number of projects implemented in different sectors and growth of gross domestic product (GDP) mainly due to the program. Indeed, the total amount invested during 2000-2010 by the top ten investing countries is USD 10,660 million. These donor countries are Australia, China, France, India, Japan, Korea, Malaysia, Norway, Thailand and Vietnam. Among these donor countries, 76.6% consists of investments from Vietnam, China and Thailand. Furthermore, the total number of projects implemented during the period is 1,280. Among them, the major sectors invested are electricity generation, mining, service, agriculture and industry/handicraft (IPD, 2010). Additionally, the growth of GDP in Laos from 2006 to 2012 was 6.5 to 8.5% per year, with these higher growth rates resulting from the development of resource sectors, such as electricity generation, mining, agriculture and services (JETRO, 2012). These developments, largely due to the GMS-ECP, also accelerated urbanization by providing basic needs such as infrastructure.
Although the GMS-ECP contributed significantly to the rate of urbanization over two decades, the time series change of its rate is not clearly known for the least developing countries in the region, such as Laos. In the case of developed countries, such as USA, relationships between vegetation amount represented by normalized difference vegetation index (NDVI) and socio-economic variables have been studied (Lo, et al., 1997; Lo, 1998; Mennis, 2006). A similar case might be true for countries like Laos, but literatures linking such changes in Laos and other developing countries in the region are sparsely documented.

Many researches have been conducted in developing countries relating to urbanization affecting land cover, but its linkage to socio-economic activities in sub-urban areas is not clearly known. One of the tools to measure the rate of urbanization over time is satellite remote sensing, which is a powerful tool to observe land cover and detect amount of areas by assigning classes without direct interaction. This would also help understand the trend of urban development and interaction between the urbanization rate and socio-economic variables. Therefore, this paper (a) determines the urbanization rate in Savannakhet, Laos from 1972 to 2013 using remote sensing imageries and (b) analyzes the relationships between the rate of urbanization with respect to socio-economic activities such as education, literature rate, mortality, environmental facilities, labor force, telecommunications and foreign direct investment (FDI). This paper is expected to contribute to rank area-specific variables for the next step, which is simulation of urbanization.

2. METHODOLOGY

The date used for this study comprised of Landsat Multispectral Scanner (MSS) and Enhanced Thematic Mapper Plus (ETM+) imageries, and socio-economic data from the ADB. The set of imageries included cloud-free parts acquired from 22 January 1973, 22 December 2000, 22 November 2001, 10 November 2002, 15 December 2003, 2 January 2005, 15 December 2006, 18 November 2007, 29 January 29 2009, 15 December 2009, 26 December 2010, 16 January 2012 and 24 January 2013. For image interpretation, the study used the Environment for Visualizing Images (ENVI) and Earth Resources Data Analysis System (ERDAS) software. The complete process of the study can be envisioned as two major steps: 1) image classification, and 2) analysis of urbanization corresponding to socio-economic activities.

2.1 Image Classification

The first step was to conduct gap-filling of the Landsat 7 ETM+ Scan Line Corrector-off (SLC-off) imageries taken in 2003, 2005, 2007, 2009, 2010, 2012 and 2013 using ERDAS. After the process, subsets were created for central Savannakhet. Supervised classification and human visual interpretation were used to identify urban areas in time series. For the supervised classification, 30 training data (regions of interest, ROIs) was created, with different colors assigned for each ROI. Maximum likelihood classification was then conducted, with 40 ground truth points selected from the latest image available from Google Earth, captured in February 2012, for accuracy assessment. The supervised classification showed 79.8 % accuracy. As visualization of the images was limited due to the SLC-off problem of the Landsat ETM+, this accuracy was considered acceptable. At the same time, for the human visual interpretation, digitization was done on images visualized by R:G:B (4:3:2) with the reference to Google Maps and the online data source in ArcMap. The urban areas generated from the supervised classification and human visual interpretation were calculated and visualized.

2.2 Analysis of Urbanization Corresponding to Socio-Economic Activities

The selected socio-economic variables and available time period of data were: 1) telephone lines (1960-2011); 2) literacy rate (youth total, percentage of people aged 15-24, 1995-2005); 3) school enrolment (primary, 1971-2011); 4) morality rate under 5 (per 1,000 live births, 1966-2011); 5) improved water sources (percentage of population with access, 1994-2010); 6) improved sanitation
facilities (percentage of population with access, 1994-2010); 7) labor force (1990-2011); and 8) FDI (net inflows in USD, 1985-2011). The data was only available at country level. However, as Savannakhet is the second largest province in Laos, it was considered that the country level data was applicable to the study area to determine correlations of parameters to the urbanization rate. Furthermore, it was difficult to obtain information on parameter-relating project implementations. Hence, this study considered the yearly data as an input activity. In order to determine scientific correlations between the socio-economic variables and rate of urbanization, regression analysis was employed using Microsoft Excel.

3. RESULTS & DISCUSSION

The results were obtained using two methods (Figure 1), with different methods showing different rates of urbanization. Such differences might be due to four technical errors and limitations, namely accuracy error during the gap-filling process, limited spatial resolutions, mixture of pixels and misclassification of objects. USGS (2004) noted that the gap-filling technique performs well in homogenous landscapes such as agricultural fields. However, it is difficult in heterogeneous landscapes, where feature sizes on the surface is smaller than the local window size (normally 19 x 19 pixels). The size of one multispectral pixel of Landsat ETM+ is 30x30 m, so 19x19 pixels means 570x570 m. As objects in the study area can be smaller than this size, the gap-filling process can be a factor which created errors. Furthermore, Weng (2012) also noted that results from image classifications are not satisfactory in terms of accuracy due to the limited spatial resolution in medium resolution satellite imagery, and the heterogeneity of urban landscape mixture of trees, grassed, and soils. Moreover, Bauer et al. (2004) noted that as bare soil is spectrally similar to impervious surface, it was misclassified as impervious surface in the case of the Minnesota. Similar to the case of Minnesota, the study area comprises of much bare land. In addition, many non-paved roads, which are largely observed in developing countries like Laos, can be misclassified as non-urban areas. In this regard, it was found the human visual interpretation was the more accurate. The results from the human visual interpretation showed increase in urban areas from 9,721 m² in 1973 to 5,258,030 m² in 2013. The urban areas identified in 2013 are 541 times larger in comparison to that in 1973. The study utilized this data for the further analysis.

![Figure 1: Comparison of urban areas calculated using the two methods.](image-url)
Table 1 shows the relationships between the rate of urbanization and socio-economic variables resulting from the regression analysis. As the accessibility of satellite imageries was limited and the availability of socio-economic data was different for the various variables, the regression equations were calculated from different ranges of time periods. The study categorized each relationship based on the size of $R$ as: 1) very strong: 0.9 to 1.0; 2) strong: 0.8 to 0.9; 3) moderate: 0.6 to 0.8; 4) weak: 0.2 to 0.6; and 5) very weak or no relationship: 0.0 to 0.2.

Table 1. Relationships between rate of urbanization and socio-economic variables.

<table>
<thead>
<tr>
<th>Num.</th>
<th>Variables</th>
<th>$R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>School enrolment (Primary)</td>
<td>0.9664</td>
</tr>
<tr>
<td>2</td>
<td>Labor force</td>
<td>0.8877</td>
</tr>
<tr>
<td>3</td>
<td>Mortality rate under 5 (per 1,000 live births)</td>
<td>0.8797</td>
</tr>
<tr>
<td>4</td>
<td>Improved water sources (percentage of population with access)</td>
<td>0.8717</td>
</tr>
<tr>
<td>5</td>
<td>Improved sanitation facilities (percentage of population with access)</td>
<td>0.8702</td>
</tr>
<tr>
<td>6</td>
<td>Telephone lines</td>
<td>0.7497</td>
</tr>
<tr>
<td>7</td>
<td>FDI, net inflows (US$)</td>
<td>0.7075</td>
</tr>
<tr>
<td>8</td>
<td>Literacy rate, youth total (people aged 15-24)</td>
<td>0.0141</td>
</tr>
</tbody>
</table>

A very strong relationship was found for school enrolment ($R=0.9664$). It can be assumed that due to the population growth from the urbanization, the provision of basic education to the increased population was highly demanded. As a result, proper educational programs were implemented in order to meet the basic educational demand.

Strong relationships were found for labor force ($R=0.8877$), mortality rate under 5 ($R=0.8797$), improved water sources ($R=0.8717$) and improved sanitation facilities ($R=0.8712$). For labor force, it is obvious that the many projects established by donor countries required huge number of labor force to maintain their productivities. Additionally, Elgin & Oyvat (2013) studied relationships between the level of urbanization and size of informal economy with cross country dataset. They found an inverted-U relationship between urbanization and the share of informal sector explained by the pull and push factors. The pull factors are factors attracting many individuals into the urban informal sector due to better employment opportunities and working conditions in comparison to rural areas. On the other hand, push factors are factors facilitating many small-scale producers in rural sectors to engage in urban informal sectors due to economic damage caused by technical development under urban industrialization. These pull and push factors play an important role during the early stage of industrialization for meeting the demand of the labor force. However, the impact of these factors tends to be reduced due to economic development of rural dwellers. As Laos may be considered to be in the early stage of industrialization, it can be said that the labor force in informal sectors will continuously increase in the next few decades. Thus, in addition to formal employment opportunities, the development of informal sectors in urban areas is also a significant factor which increases the labor force. For mortality rate under 5, Gong et al. (2012)’s study on urbanization and health, conducted in China, also pointed out a positive relationship between them. This is explained by: 1) difficulty in access to health care, vaccination coverage and insurance among migrant populations; 2) poor urban environmental quality, such as air and water pollution; and 3) traffic-related accidents. The results of this study can also be explained by the circumstance observed in China. It can be rationally assumed that with economic growth, urbanization may become an opportunity to largely pay attention to basic human needs such health and environmental facility developments, and basic facilities, including water sources and sanitation facilities.

Moderate relationships were identified for telephone lines ($R=0.7497$) and FDI ($R=0.7075$). It can be assumed that the relationship with telephone line is not so significant due to the higher distribution of mobile phones in comparison to telephone lines in Laos. In fact, the mobile cellular subscription (per 100 people) in Laos was reported at 3.6 in 2004 and 64.56 in 2010 (Trading Economics, 2013), which is approximately 18 times higher than it was in 2004. For the FDI, Sabu (2013) found a positive relationship between FDI growth and urbanization in China, but it is not so significant in this study.
This difference can be caused by differences in targeted investment sectors in China and Laos. The Chinese FDI is highly related to export-oriented industries that require the establishment of many manufacturing industries. On the other hand, the main sectors largely invested in Laos are electricity generation, mining, services, agriculture and industry/handicraft, which have not been largely carried out in the study area. Therefore, the relationship between two was not so significant in this study.

Very weak or no relationship was identified for literature rate (total youth, $R=0.0141$). As the data for the regression model was calculated from the data for 2000 to 2011, the study interpreted that literacy rate among youth had already been developed several decades before. Indeed, the literacy rate of youth showed 71.13% in 1995, 80.6% in 2000; 78.46% in 2001 and 83.93% in 2005 (Index Mundi, 2013).

4. CONCLUSION

This study examined the change in the rate of urbanization in time series utilizing Landsat MSS and ETM+ remote sensing data obtained from 1973 to 2013. The results from the human visual interpretation showed increase in urban areas from 9,721 m$^2$ in 1973 to 5,258,030 m$^2$ in 2013, which is 541 times larger in comparison to that in 1973. The socio-economic variables, such as school enrolment, labor force, mortality rate, water sources and sanitation facilities, were highly correlated with the rate of urbanization during the period. Identifying the highly correlated socio-economic variables with urbanization rate will enable us to conduct a further urbanization simulation, which will help in designing policies for sustainable development.

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MULTI-TEMPORAL SATELLITE IMAGERY FOR URBAN EXPANSION ASSESSMENT OF SHARJAH CITY, UAE

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ABSTRACT

Change detection is the process of identifying differences in land cover over time. As human and natural forces continue to alter the landscape, it is important to develop monitoring methods to assess and quantify these changes. Recent advances in satellite imagery, in terms of improved spatial and temporal resolutions, are allowing for efficient identification of change patterns and the prediction of areas of growth. Sharjah City is the third largest and most populous city in the United Arab Emirates (UAE). It is located along the northern coast of the Persian Gulf on the Arabian Peninsula. After the discovery of oil in UAE and its export in the last four decades, it experienced very rapid growth in industry, economy and population. The main purpose of this study is to detect urban development in Sharjah City by detecting and registering linear features in multi-temporal Landsat images. This paper used linear features for image registration that were chosen since they can be reliably extracted from imagery with significantly different geometric and radiometric properties. Derived edges from the registered images were used as the basis for change detection via image registration and pixel–pixel subtraction. Straight-line segments were used for accurate co-registration as well as the main element for a reliable change detection procedure. The results illustrated that the highest range of growth represented by linear features (building and roads) was accrued between 1976 and 1987, which consists of 36.24 % of the total urban features in Sharjah City. Moreover, the result showed that between 1976 and 2010, the cumulative urban expansion inside Sharjah City is 71.9 %.

Keywords: Change detection; satellite imagery; temporal resolution; image registration; urban expansion.

1. INTRODUCTION

The demand for up-to-date geographic data is increasing due to rapid changes to the landscape that are taking place as a result of nature and/or human actions. Such changes have to be accurately and reliably inventoried to fully understand the physical and human processes at work (Estes, 1992). Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). It involves the ability to quantify changes using multi-resolution, multi-spectral and/or multi-source imagery captured at different times. Traditional change detection studies are based on visual/manual comparison of temporal datasets (such as satellite scenes, aerial images, maps, etc.). However, the huge flux of imagery that is being captured by an ever increasing number of earth observing satellites necessitates the development of automatic, reliable, and fast change detection techniques. Such techniques are essential to reduce the high cost associated with spatial data updating activities. Several change detection methods have been developed and reported in the literature (Singh, 1989; Dowman, 1998; Bruzzone & Prieto, 2000; Al-Ruzouq & Habib, 2012). These procedures are based on image subtraction, image ratio, change vector analysis, principle component analysis, neural network and morphological mathematics.

The main purpose of this study is to detect urban development in the city of Sharjah City, United Arab Emirates (UAE) by detecting and registering linear features in multi-temporal Landsat images. This paper uses a registration methodology that is based on the Modified Iterated Hough Transform (MIHT) (Habib & Kelley, 2001a, b; Habib & Al-Ruzouq, 2004, 2012) for simultaneously estimating
the parameters of the registration transformation function while establishing correspondence between conjugate straight-line segments in an image pair. Derived edges from the registered images are used as the basis for change detection via image registration and pixel–pixel subtraction.

2. GEOSPATIAL DATA

2.1 Study Area

Sharjah City is located along the northern coast of the Persian Gulf on the Arabian Peninsula with a central coordinate of 25.3° N, 55.5° E (Figure 1). It is the capital and largest city in the Emirates of Sharjah. It located in a dry, hot region, with daily high temperatures of 24-42 °C and daily main temperatures of 18-34 °C. The rainy month is typically December to February, with average rainfall of approximately 100 mm/year. The rainfall in dry years does not generally exceed 40 mm/year and 200 mm/year in heavy rain years.

Figure 1: Location of the study area: (a) UAE map   (b) Landsat image of Sharjah  (b) The study area within Sharjah.
2.2 Dataset

The data used in this research included a diversity of satellite images with different radiometric and geometric resolutions captured in different years. The data was used for image registration and change detection. Table 1 lists the source of each image including year of capture and spatial resolution in m. Figure 2(a) shows samples of the Landsat images for the study area for the years 1976 and 2000.

Table 1: Multi-temporal images used for this study.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Year</th>
<th>Resolution (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat Multispectral Scanner (MSS)</td>
<td>1976</td>
<td>79</td>
</tr>
<tr>
<td>Landsat Thematic Mapper (TM)</td>
<td>1987</td>
<td>60</td>
</tr>
<tr>
<td>Landsat Thematic Mapper (TM)</td>
<td>2000</td>
<td>30</td>
</tr>
<tr>
<td>Landsat Thematic Mapper (TM)</td>
<td>2007</td>
<td>30</td>
</tr>
<tr>
<td>Landsat Enhanced Thematic Mapper (ETM)</td>
<td>2010</td>
<td>15</td>
</tr>
</tbody>
</table>

3. METHODOLOGY

3.1 Overview

In this paper, linear feature detection, image registration and pixel-pixel subtraction were implemented using Landsat images that have different spatial and temporal resolution. Linear features (straight-line segments) have high semantics and can be reliably extracted from the images. These linear features (streets and buildings in urban areas) were used as the basis for change detection. Distinguished and well distributed points (main intersections and corners of buildings) were manually digitized from the multi-temporal Landsat images to perform the registration process, where 10-15 points (end points of the linear features) were used to drive the transformation parameters needed for the image registration. It should be noted that accurate registration of multi-temporal imagery is considered as one of the most important component of an accurate and reliable change detection procedure (Al-Ruzouq & Habib, 2012).

Having established the transformation function between the images, the input images were resampled into the reference frame associated with the reference images. Figure 2(a) shows an example of clipped Landsat images after the image registration and resampling processes. The resampling was followed by applying canny edge detection and majority filtering to both images. Then, the resulting images were subtracted to produce a change image, which is enhanced by re-application of the majority filter. Section 3.2 will discuss the theory and principles of the image registration process. The change detection criteria and stages will be discussed in Section 3.3.

3.2 Image Registration

An image registration process aims at combining data and/or information from multiple sensors in order to achieve improved accuracies and better inference about the environment than could be attained through the use of a single sensor. An effective automated image registration methodology must deal with four issues, namely registration primitives, transformation function, similarity measure and matching strategy (Al-Ruzouq & Habib, 2004).

In order to carry out the registration process, a decision had to be made regarding the choice of the appropriate primitives (for example, distinct points, linear features or homogeneous regions). In this research, straight-line segments were used as the registration primitives (Figure 1).

The second issue in a registration procedure is concerned with establishing the transformation function that mathematically describes the mapping function between the imagery in question. In
other words, given a pair of images, the reference and input images, the transformation function attempts to properly overlay these images. Habib et al., (2001a, b) demonstrated that affine transformation (Equation 1) can be used as the registration transformation function for imagery captured by satellite imaging systems with narrow angular field of view over relatively flat terrain as compared to the flying height.

\[
\begin{bmatrix}
  x' \\
  y'
\end{bmatrix} = \begin{bmatrix}
  a_0 & a_1 & a_2 \\
  b_0 & b_1 & b_2
\end{bmatrix} \begin{bmatrix}
  x \\
  y
\end{bmatrix}
\]

(1)

where: \((x, y)\) denotes the coordinates of a point in the reference image, and;
\((x', y')\) denotes the coordinates of the conjugate point in the input image.

The next step in the registration process is the selection of the similarity measure, which mathematically describes the necessary constraints for ensuring the correspondence of the conjugate primitives. The similarity measure formulation depends on the selected registration primitives and their respective attributes. In this work, the registration primitives, straight-lines, will be represented by their end points, which need not be conjugate.

Let us assume that a line segment \(A\) in the reference image corresponds to the line segment \(B\) in the input image. The similarity measure should mathematically describe the fact that the line segment \(A\) will coincide with the corresponding line segment \(B\) after applying the transformation function relating the reference and input images. Such a measure can be derived by forcing the normal distances between the end points of a line segment in the reference image, after applying the transformation function, and the corresponding line segment in the input image to be zero. Equation 2 mathematically describes such a constraint for one of the end points of the line segment in the reference image.

\[x'_1 \cdot \cos \theta + y'_1 \cdot \sin \theta - \rho = 0\]

(2)

where: \((\rho, \theta)\) are the polar coordinates representing the line segment \(B\) in the input image, and;
\((x'_1, y'_1)\) are the transformed coordinates of Point 1 in the reference image after applying the registration transformation function.

Another constraint of the form in Equation 2 can be written for Point 2 along the line-segment in the reference image. To automate the solution of the registration problem, a controlling framework that utilizes the primitives, similarity measure and transformation function must be established. This framework is usually referred to as the matching strategy. In this research, MIHT was used as the matching strategy. Such a methodology is attractive since it allows for simultaneous matching and parameter estimation. Moreover, it does not require complete correspondence between the primitives in the reference and input images. MIHT has been successfully implemented in several photogrammetric operations, such as automatic single photo resection and relative orientation (Habib et al., 2001a, b; Al-Ruzzouq & Habib, 2012).

3.3 Change Detection

After deriving the parameters of the registration transformation function, one of the images can be resampled into the reference frame associated with the other one. Within the resampled images, corresponding pixels are assumed to point at the same object space feature. Therefore, a simple pixel-by-pixel comparison/differencing between the resampled images could be used to highlight object space changes. However, radiometric differences should be expected as a result of varying atmospheric conditions and/or different sensor types. The effect of these differences can be reduced by applying intensity normalization techniques to the images in question (e.g., to ensure that they...
have the same intensity mean and variance values). One can argue that this procedure would be still unreliable since it would be affected by the noise and the spectral properties associated with the input imagery (Canny, 1986; Agouris et al., 2000; Cavallaro & Touradj, 2001).

Instead of working with the original images, after intensity modification, one can use derived edge images as a basis for the change detection procedure. Utilizing the edge images has two advantages. First, derived edges are robust to possible radiometric differences between the registered images (e.g., due to noise and/or different spectral properties). Furthermore, the edges would correspond to interesting features (e.g., building boundaries, roads, trails, etc.). Therefore, comparing edge images will be useful in outlining the amount of urbanization activities, which is one of the most important objectives of change detection exercises (Al-Ruzouq & Habib, 2004).

The suggested change detection methodology started by extracting edge cells using canny edge detector (Canny, 1986). Figure 2(b) shows samples of derived edges for the study area at different years. To compensate for small geometric differences between the imagery (in the order of few pixels), a majority filer is used to fill small gaps within an area with numerous edges, as well as eliminate isolated edges (Figure 2(c)).

The filtered images highlight areas with interesting features since they would lead to a dense distribution of edge cells. Afterwards, the filtered images were subtracted to highlight areas of change. Finally, a majority filter was applied to the difference image to eliminate small areas (since changes/no-changes are expected to be locally spread, i.e., they are not isolated).

4. RESULTS

Figure 3 shows the difference image from 1987 until 2010, where white areas indicate changes while black areas indicate parts with no change. Figure 4 shows the clipped Landsat images for the study area for the years 1976, 1987 and 2000, and the respective change images, where white pixels represent changes. Simple statistics show that highest range of growth represented by linear features (building and roads) was accrued between 1976 and 1987, which consists of 36.24% of the total urban features in Sharjah City. Moreover, the results show that between 1976 and 2010, the cumulative urban expansion inside Sharjah City is 71.9%.

5. CONCLUSION

This paper presented a procedure for image registration and detecting changes between multi-temporal satellite images. The approach was tested for Sharjah City, which showed its effectiveness in registering and detecting changes among multi-temporal and multi-resolution imagery. The MIHT procedure was used for automatic registration of multi-source imagery with varying geometric and radiometric properties. The presented approach used linear features (straight-line segments) as the registration primitives since they can be reliably extracted from the images. In order to avoid the effect of possible radiometric differences between the registered images, due to different atmospheric conditions, noise and/or different spectral properties, the change detection implemented was based on derived edge images. The use of edge images is attractive since it would lead to an effective detection of urbanization activities since they would lead to a dense distribution of edge cells. In addition, a majority filter was applied to compensate for small registration errors as well as eliminating small gaps and isolated edges. The images were then subtracted to produce a change image, which could be enhanced by applying a majority filter to remove small regions. The change detection results were found to be consistent with those visually identified. Future research will concentrate on using high resolution images for change detection, while at the same time establishing ground truths for quantitative evaluation of the suggested approach.
Figure 2: (a) Cropped Landsat images for the years 1976 and 2000. (b) Derived edges. (c) The derived edges after applying the majority filter.

Figure 3: Difference image for the study area for the years 1987 and 2010.
Figure 4: (a) Clipped Landsat images for the study area for the years 1976, 1987 and 2010. (b) Change detection images, where white pixels represent changes.

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LAND USE AND LAND COVER CHANGE DETECTION USING REMOTE SENSING AND GIS TECHNOLOGIES: A CASE STUDY OF MIRzapur UNION, GAZIPUR DISTRICT, BANGLADESH

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ABSTRACT

A study was conducted with a view to identify and quantify the changes in land use and land cover that occurred during the last 20 years at Mirzapur Union, Gazipur district, Bangladesh using remote sensing (RS) and geographical information systems (GIS) technologies. Two Landsat TM images for 1989 and 2009 with 30 m spatial resolution were used to determine the temporal land cover changes. Subsequently, ground verification was conducted in the study site. The study revealed that forests and water bodies decreased by 20.29 and 6.25% respectively, while settlements were found to have increased by 28.64%. In the same period of time, bare lands were found to have increased by 20.91% due to the effect of clearing of forests which were not replanted again. A lot of new infrastructures had been built in this period and the population doubled, resulting in the deforestation of the Sal forest (Shorea robusta). The most prominent features are the emergence of brick fields and various industries. This study demonstrates the usefulness of RS and GIS technologies for resource management and urban planning.

Keywords: Land use and land cover; Landsat imageries; georeferencing; change detection; deforestation.

1. INTRODUCTION

Land is one of the most important non-renewable natural resources. As the world population increases, it exerts pressure on land, which is ultimately associated with agricultural demand, urbanization, economic development, science and technology, etc. Timely and precise information on land use and land cover change detection of the earth’s surface is extremely important for understanding relationships and interactions between human and natural phenomena for better management of natural resources and in decision making. Inventory and monitoring of land use and land cover changes are indispensable aspects for further understanding of change mechanisms and modeling the impact of change on the environment and associated ecosystems at different scales (William et al., 1994; Tunner et al., 1995). To detect land use and land cover change, a comparison of two or more satellite images acquired at different times can be used to evaluate the temporal or spectral reflectance differences that have occurred between them (Yuan & Elvidge, 1998).

Bangladesh is basically an agrarian country, characterized by diversified landscapes. Hence, land resources are the prime assets of this country, though the land-man ratio is very low, estimated to be 0.06 ha per person (FAO, 2013). The land resources of the country are divided into two categories, agricultural and non-agricultural lands. Hasan et al. (2013) reported on the declining trends of
The increasing trends of non-agricultural lands (rural settlements, urban and industrial, etc.) were 8.17, 12.31 and 16.47% for 1976, 2000 and 2010 respectively. The extent of non-agricultural land increased by 2.13 and 3.43% for the periods of 1976-2000 and 2000-2010 respectively. The conversion rate of agricultural to non-agricultural land is about 1% per year (Planning Commission, 2009), which is alarming in respect to the total crop production and food security in Bangladesh (Rahman & Hasan, 2003). Thus, land use and land cover change detection study in Bangladesh is very much urgent in enhancing the proper policy planning using advanced tools.

The aim of this study is to monitor and analyze the spatio-temporal land use and land cover change patterns in Mirzapur Union, Gazipur district, Bangladesh using multi-temporal Landsat imageries for the past 20 years. This study demonstrates the usefulness of remote sensing (RS) and geographical information systems (GIS) technologies for resource management and urban planning.

2. MATERIALS AND METHODS

The study area (Figure 1) was selected because migration of huge population as it is very near to Dhaka and is a good site for an urban development center. As a result of population pressure, the local people are destroying forests, trees and valuable cultivable land to develop various industries and brick fields. As a result, the forest area is gradually decreasing and the environment is changing significantly. Considering the above situations, two Landsat Thematic Mapper (TM) images, for 1989 and 2009, with resolution of 30 m (projection: Bangladesh Transverse Mercator) were used in this study. Some secondary data sources were also used, such as topographical, soil and physiographic maps. The image related methodology adopted for this study involved digital image processing (DIP) and GIS analyses (Figure 2). DIP analysis was carried out using a computer system having data layer software configuration, with the ERDAS IMAGINE image processing software used for georeferencing, classification and enhancement of the images, and other related processing. The Arc Info software was used for digitizing, displaying and analyzing all the vector layers. The Landsat images were preprocessed to remove data errors and anomalies. The DIP system was used to determine the land covers.

2.1 Georeferencing

A sufficient number of ground control points (GCPs), which were readily identifiable on the pre-rectified image, were selected for calculation of a least-square fit, and the results were then used to adjust the image to image coordinates. The preferred GCPs were taken from recognizable, permanent features, such as road intersections, ponds and large buildings, and the points were well dispersed for accurate rectification. The images were projected on to a plane, and then rotated and scaled to a map projection system. For each image transformation, the root mean square (RMS) error was calculated, with the maximum being 1.5 pixels. This corresponds to a ground distance of 45 m for the TM images. Using this procedure, each raw satellite image was resampled, using the nearest neighbor algorithm, and transformed into a file referenced to the Universal Transverse Mercator (UTM) projection.

2.2 Classification

A digital classification scheme was developed to categorize five major land cover types (settlement, water body, forest, bare land and valley). The Landsat images were classified using image processing techniques to enable the assignment of land cover classes to areas of similar spectral characteristics.
Both supervised and unsupervised methods of classification were done. The unsupervised classification was based on the ISODATA algorithm available in the ERDAS Imagine software. The supervised classification method was based on the maximum likelihood algorithm. Figure 3 depicts the techniques used to obtain the land cover classes in vector form.

Figure 1: Location map of the study area (Mirzapur Union, Gazipur District).
Figure 2: Schematic representation of the methods and procedures used in this study.
Figure 3: Techniques used to obtain land cover classes.

The five land cover classes were assigned to each of the two images. In order to verify the land cover classes in the field, the authenticity of the class boundaries were checked. The located positions’ coordinates were noted down and the geo-features’ characteristics were recorded in the field. These records were independently examined to determine if the interpreted classes in the maps were accurate. Area calculation of the classes was then performed for both the images.

3. RESULTS AND DISCUSSION

Classified images of land use and land cover for 1989 and 2009 were generated for the five classes (Figure 4). The changes in the classes over the 20 year period are shown in Figure 5.

The forest class consisted of mainly the Sal forest (Shorea Robusta). Adjacent crop fields and trees were included in the settlement class because of the lower resolution of the Landsat images. Forests were identified in the images due to their color and by the knowledge of the position of the Sal forest in the study area. In 1989, about 2,986.74 ha or 34.35% of the study area was found to be occupied with forests, which declined to 2,380.59 ha (27.38%) in 2009. Within this 20 year period, the forest area decreased by 606.01 ha (20.29%). The main cause of deforestation is the expansion of agricultural land, which resulted in clearing of forests, especially in the plane areas where the highest population density exists. After the deforestation, some parts of the Madhupur forest had been converted to banana and pineapple plantations. In addition, some parts of the deforested area had been converted into rubber gardens by the government. Population and economic pressures are two prominent factors that lead to the clearing of the forests (Uddin & Gurung, 2010).

Settlements or homesteads appeared in all parts of the study area, and were found to have lean, semi-compact, compact and semi-sprinkled patterns. The settlement class includes houses, markets, shops, adjacent lands and associated trees, crop land, roads, and industrial areas. Extensive areas of settlement were found to be mixed with vegetation. In the Landsat images, settlements appeared as mixed color. In 1989, the area occupied by settlements was 3,959.55 ha (45.54%), while in 2009, it was 5,093.10 ha
or (58.58%) Hence, settlements increased by 28.64% between 1989 and 2009. The population census report also indicated the increasing trends of population for these years (BBS, 2009).

Figure 4: Land use and land cover maps for the study area for the years (a) 1989 and (b) 2009.
Water bodies were identified in the Landsat images by dark tones (blue and black color) that reflect very little amounts of light, which varies based on turbidity (the higher the turbidity, the higher will be the light reflectance and lighter will be the color). Water bodies were also identified by their shape, as rivers appear as meandering and ponds are rectangular in shape. In 1989, water bodies occupied 445.41 ha (5.12%) of study area. In 2009, the area occupied by water bodies was 413.46 ha (4.8%). Thus, water bodies were found to have decreased by 31.95 ha (6.25%). The results are well in accordance with the findings of SRDI (2009), Momtaz (2009) and Akter (2009). SPARRSO (1997, 2006) reported a decreasing trend of water body area in Savar Upazila, Bangladesh over the period. This change might have taken place due to sedimentation/siltation, shifting of water flow direction and rising river beds.

Bare lands showed a white signature and fine grain size of the sands forming a smooth surface. The low moisture content of bare soil (due to dry season) appeared to be in brighter tone than that of the other features. In 1989, the bare land area was 669.33 ha (7.7%), while in 2009, it was 809.91 ha (9.31%). This indicates that bare lands increased by 140.58 ha (20.91%) during the last 20 years. The increase of bare lands might be due to the clearing of forest areas for fuel and other purposes.

Lowland valleys were identified in the images due to its shape. The area of valleys in 1989 was 1,856.52 ha (21.35%), whereas in 2009, the area was 1,156.86 ha (13.30%), which was found to have decreased by 699.66 ha (37.71%). In most cases, these valley areas were occupied by settlements due to increasing pressure of population. Brick fields were mainly observed in both sides of the bank of the Lubundaha river, where parts of the wetland were turned into bare lands. In these areas, brick fields are increasing day by day as urbanization is fast growing in the study area.

4. CONCLUSION

Significant changes were detected in land use and land cover in Mirzapur Union during the last 20 years (1989-2009). These changes occurred in different land covers, such as forests and water bodies, which decreased by 20.29 and 6.25% respectively; and settlements and bare lands, which increased by
28.64% and 20.91% respectively. All of these changes were due to the increase of population and unplanned urbanization destroying the local forest resources.

REFERENCES


A NEW METHOD TO DETERMINE ERODED AREAS IN ARID ENVIRONMENTS USING LANDSAT IMAGERY AND LITHOLOGICAL DATA

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ABSTRACT

Erosion (by water or wind) is an increasing problem for many local authorities and government agencies throughout the world. The identification of eroded areas in arid and humid regions can be very useful for environmental planning, and can help reduce soil and sediment degradation in these regions. In this work, we present a new method to determine eroded areas in arid environments using Landsat imagery and lithological data. The lithological data was collected in the field using Global Positioning System (GPS) checkpoints and geological maps. For this, two lithological maps of the study area for two different years, initial time (t₁, 1987) and final time (t₂, 2011), were analysed to determine lithological data change. The two maps were obtained by applying the maximum likelihood algorithm on Landsat images for the respective years. After image classification and validation, a change detection technique was adopted to determine the eroded areas. The method was applied on the northern part of the Atlantic Sahara desert to confirm its potentiality.

Keywords: Eroded areas; lithological data; Landsat imagery; maximum likelihood algorithm; change detection

1. INTRODUCTION

Erosion is any process, natural or man-made, by which material is removed from one location and deposited to another. In order for erosion to occur, an erodible material must be exposed to some form of energy or eroding force. Erosion is one of the principal mechanisms of desertification at national and regional levels. It is an increasing problem for many local authorities and government agencies throughout the world. The identification of eroded areas in national and regional levels can be very useful for environmental planning, and can help reduce soil and sediment degradation in this region.

The use of remote sensing techniques has been shown to have potential for identification of eroded surfaces at regional scales (Lambin, 1996; Lambin & Ehrlich, 1997; Haboudane et al., 2002; King et al., 2005; Lu et al., 2007; Alatorre & Begueria, 2009; El Baroudy, 2011). Several methodologies have been applied to mapping of eroded areas, including spectral data (Haboudane et al., 2002; Lu et al., 2007; Lenney et al., 1996), vegetation indices (Lambin & Ehrlich, 1997; Tripathy et al., 1996; Prince et al., 2009), and combinations of remote sensing and morphological data (Liberti et al., 2009).

Arid environments cover more than one fifth of the Earth’s land, and they are found on every continent. These areas exist under a moisture deficit, which means they can frequently lose more moisture through evaporation than they receive from annual precipitation. In this work, we present a new method to determine eroded areas in arid environments using Landsat imagery and lithological
data. Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) imagery have been used to monitor changes in landforms and land degradation mechanisms (Yang et al., 2007), and forest cover change and deforestation mechanisms (Zhang et al., 2005; Townshend et al., 2012). Furthermore, many studies have shown the importance of Landsat imagery for lithological mapping in arid environments (Sultan et al., 1987; Gad & Kusky, 2006). However, thus far, no study has explored the use of lithological data to determine eroded areas.

2. METHODOLOGY

The methodology for this study is shown in Figure 1. The lithological data was collected in the field using Global Positioning System (GPS) checkpoints and geological maps. Two lithological maps of the study area for the years 1987 and 2011 were analyzed to determine the lithological data change. The two maps were obtained by applying the maximum likelihood algorithm on Landsat images for the respective years. This classification was adopted for both sets of Landsat images by delimiting polygons around representative points collected in the field. After image classification and validation, a change detection technique was adopted to determine the eroded areas.

![Figure 1: The methodology of this study.](image_url)
3. CASE OF STUDY: THE NORTHERN PART OF THE ATLANTIC SAHARA DESERT (SW OF MOROCCO)

3.1 Study Area

The study area is located in the northern part of the Atlantic Sahara desert (southwest of Morocco). It is a vast coastal platform, extending from 12° 0’ 35” to 12° 23’ 55” W in longitude and 27° 53’ 6” to 28° 8’ 27” N in latitude (Figure 2).

Climatically, this region is a part of the Boreal domain of maritime trade winds, where precipitation is less than potential evapotranspiration. This wind is one of the most regular winds in the world (Elbelrhiti, 2005). Thus, the dry season extends for about 12 months. The amount of precipitation is about 33 mm per year. The yearly mean maximum and minimum air temperature are 26 and 19 ºC respectively. The extreme aridity of this area is primarily caused by large-scale atmospheric subsidence due to the Açores anticyclone.

3.2 Lithological Data

The surface of the Akhfinir region is dominated by flat layering of hard rocks at the surface (Moghrebian Sandstone-Limestone Slab). This flagstone is overlain by Pleistocene consolidated dunes and broken in another place, by a sabkha depression where Miocene marls and silts are deposed.

In this region, eight facies classes were distinguished: sand, beach rocks, salt crust, sand-limestone slab, alluvium facies, marl and silt, limestone, and mud. The descriptions of theses facies classes are presented in Table 1.
### Table 1: Description of different facies classes in the study area.

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
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<tbody>
<tr>
<td>Sand</td>
<td>Principal component of dunes</td>
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<tr>
<td>Salt crust</td>
<td>Sabkha components, is sand and clay cimented by the alkaline minerals</td>
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<tr>
<td>Beach rocks</td>
<td>Pliocene terrigenous sandstones facies</td>
</tr>
<tr>
<td>Sand-limestone slab</td>
<td>Hard rock Moghrebian facies</td>
</tr>
<tr>
<td>Alluvium facies</td>
<td>Part of the recent Pleistocene sediments, is conglomeratics sand</td>
</tr>
<tr>
<td>Marl and silt</td>
<td>Miocene transgressive deposit of sabkhas</td>
</tr>
<tr>
<td>Limestone</td>
<td>Senonian (Later Cretaceous) transgressive deposit</td>
</tr>
<tr>
<td>Mud</td>
<td>Principal component, with sand, in mudflats and salt marshes</td>
</tr>
</tbody>
</table>

### 3.3 Results

The results of the classification are shown in Figure 3. The results obtained from the application of confusion matrix to the validation data show that all of the facies are better classified, with high overall prediction accuracy, and low rates of both commission and omission errors.
Change detection statistics and difference map operations were carried out for the classification results of 1987 and 2011 images in order to produce the statistical data about the spatial distribution of different lithological classes (Table 2) and an eroded areas map (Figure 4). The statistical change results were beneficial to ascertain the reasons behind the observed changes.

4. CONCLUSION

The objective of this study was to determine eroded areas in arid environments using a new method based on Landsat imagery and lithological data. In this study, a change detection technique was applied on two classified lithological maps to provide an eroded areas map. Furthermore, the statistical change results were beneficial to ascertain the reasons behind the observed changes. The results of the application of this method on the northern part of the Atlantic Sahara desert confirmed its potentiality. The obtained erosion map could be used as a decision tool for sediment erosion management.

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Change 16.13 -19.5 33.8 -46.38 0.84 11.01 47.53 -6.25 -37.23

Figure 4: Eroded areas in the Akhfinir region.
ACKNOWLEDGEMENT

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MONITORING TEMPORAL VEGETATION CHANGES IN LAO TROPICAL FORESTS

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ABSTRACT

Studies on changes in vegetation are essential for understanding the interaction between humans and the environment. These studies provide key information for land use assessment, terrestrial ecosystem monitoring, carbon flux modelling and impacts of global climate change. The primary purpose of this study was to assess whether it is possible to detect temporal vegetation changes in tropical forests using Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery. The study investigated the annual vegetation phenological response of dominant land cover types across the study area in southern Lao PDR, and its relationship to seasonal precipitation and temperature. Improved understanding of intra-annual patterns of vegetation variation was useful to detect longer term changes in vegetation. The breaks for additive season and trend (BFAST) approach was implemented to detect changes in land cover types from 2001-2012. We used the enhanced vegetation index (EVI) data from MODIS (MOD13Q1 products) high resolution multispectral satellite images accessed through Google Earth, and local monthly rainfall and temperature data. EVI documented the annual seasonal growth of vegetation and clearly distinguished the characteristic phenologies of four different land cover types: native forest, plantations, agriculture and mixed wooded/cleared areas. Native forests maintained high EVI throughout the year, while plantations, wooded/cleared areas and agriculture showed greater inter-annual variation, with minimum EVI at the end of the dry season in April and maximum EVI in September-October, around two months after the wet season peak in rainfall. The BFAST analysis detected abrupt temporal changes in vegetation in the tropical forests, especially in large conversions of mixed wooded/cleared area into plantation. Within the study area from 2001-2012 there was an overall trend of decreasing vegetation cover in native forests and mixed wooded/cleared lands, and by contrast an increase in cover and area of plantations after 2008.

Keywords: Lao tropical land covers; vegetation changes; breaks for additive season and trend (BFAST); Moderate Resolution Imaging Spectroradiometer (MODIS); enhanced vegetation index (EVI).

1. INTRODUCTION

Forests play important roles in balancing the global climate, storing or exchanging terrestrial carbon, maintaining hydrological systems, and in providing biodiversity and habitats. Most international attention has been given to changes in forest resources because they are associated with greenhouse gas emissions, land degradation and loss of biodiversity (Setiawan et al., 2014). Information on spatial and temporal changes in vegetation at local, regional and global scales is important for improving our understanding of human - environment interactions (Zhang et al., 2005; Chernetshy et al., 2011; Huang & Friedl, 2014), including alterations to terrestrial ecosystems, carbon fluxes and global climate (Viña et al., 2012; Papes et al., 2013).
Studies of vegetation phenology could provide essential information to support modelling and monitoring of climate change. This information is useful for detecting and monitoring regional and global environmental changes as vegetation response is sensitively interrelated to environmental and climate influences (Jeganathan et al., 2014), such as temperature, soil moisture and human activities (Zhang et al., 2005). Moreover, monitoring and forecasting changes in phenology is useful to understand the response of vegetation under changing climatic conditions (Prabakaran et al., 2013).

Although several studies have been done in a wide range of environments, little is known about changes in tropical forest regions (Huete et al., 2008; Setiawan et al., 2014). The tropical forest is one of the most complex ecosystems on our planet (Avitabile et al., 2012). Acquisition of adequate information from on-ground observations and samples is difficult. Furthermore, these generally only provide species-specific information for a limited number of sample sites and lack comprehensive spatial coverage. Information captured by earth-observing remote sensing instruments provides opportunities to overcome this challenge (Östendorf et al., 2001; Setiawan et al., 2014). Information from space is essential for analysing the spatial and temporal patterns of vegetation from local to regional and continental scales (Verbesselt et al., 2010; Viña et al., 2012; Forkel et al., 2013). For example, multiple-year satellite images allow us to monitor characteristics and responses of vegetation over time, including changing events and processes. Changes in vegetation can be analysed using remote sensing data time series, such as normalised difference vegetation index (NDVI) (Forkel et al., 2013; Klein et al., 2012; Mao et al., 2011) and enhanced vegetation index (EVI) (Coops et al., 2009; Moreau & Defourny, 2012).

Several remote sensing approaches have been tested and successfully applied to study changes in vegetation composition, cover and structure (Coops et al., 2009). They have used a diversity of satellite datasets, with varying spatiotemporal resolutions, and have employed a range of statistical methods (Forkel et al., 2013). Amongst these, the breaks for additive season and trend (BFAST) approach is a powerful technique to detect gradual and abrupt changes in satellite data time series. It has been successfully tested in south eastern Australia and South Somalia (Verbesselt et al., 2010; Verbesselt et al., 2012). However, little is known about the performance of BFAST in tropical forests. Monitoring vegetation in this region using satellite remote sensing is challenging due to atmospheric effects such as frequent cloud cover and high levels of aerosols. As a result, vegetation phenology and trends in cover in tropical forests are not well documented (Moreau & Defourny, 2012).

Therefore, the primary purpose of this study was to assess the detectability of intra and inter-annual changes in the tropical forests and vegetation cover across a study area in the southern part of Lao PDR, through analysis of Moderate Resolution Imaging Spectroradiometer (MODIS) satellite vegetation index data. The response of vegetation phenology to monthly average precipitation and temperature was investigated, providing understanding of intra-annual response, against which longer term changes in vegetation could be detected. The BFAST approach was used to detect vegetation changes in land cover types between 2001 and 2012.

2. MATERIALS AND METHOD

2.1 Study Area

The study area was situated in the north of Champasack Province, in the south of Lao PDR. It covered an area of approximately 1,000 km², from 14°99'00"N to 15°41'00"N latitude and from 105°77'00" E to 106°00'00" E longitude (Figure 1). The study area partially covered five districts, Xanasomboun Pakse, Phonetong, Phatumphone and Bacheinghalsouk, and also included about 2% of the Dong Houa Sao National Biodiversity Conservation Area. Land use throughout the area is mixed, with predominance of land under plantations, mixed wooded/cleared areas, agriculture (mainly irrigated rice) and native forests. While some of the study area is mountainous (approximately 10%), the majority is relatively flat lowlands (approximately 90%). The altitude ranges from 100-950 m, but the majority of land is between 100-130 m above sea level. There are two distinct seasons; rainy (May-
October) and dry (November-April). During the rainy season, it is often windy, humidity is high and most of the 2,279 mm average annual rainfall occurs. In the dry season, conditions are mostly sunny, average temperatures are 28-31°C and there is little rainfall.

Figure 1: Location of the study area in the north of Champasack Province, Lao PDR.

2.2 Data

Two primary sources of data were used in this study; MODIS EVI and high resolution colour satellite imagery from Google Earth. MODIS EVI is a 16-day composite product (MOD13Q1) with a spatial resolution of 250 m and is available from 2001-2012. NDVI and EVI have been commonly used to study changes in vegetation in tropical regions. However, we used only MODIS EVI in this study. EVI was introduced by the MODIS Land Discipline Group as a standard satellite vegetation product for MODIS Terra and Aqua. This algorithm has improved sensitivity to high biomass regions and improved vegetation monitoring through de-coupling of the canopy background signal and reduction in atmospheric influences (Zhang et al., 2005; Huete et al., 2006; Huete et al., 2008; Coops et al., 2009; Ma et al., 2013; Senf et al., 2013). Its formula is as follows:

\[
EVI = 2.5 \times \frac{(P_{\text{NIR}} - P_{\text{red}})}{(1 + P_{\text{NIR}} + 6 \times P_{\text{NIR}} - 7.5 \times P_{\text{blue}})}
\]

where \(P_{\text{NIR}}, P_{\text{red}}\) and \(P_{\text{blue}}\) are near infrared, red and blue reflectances respectively.
The study area was covered by MODIS tile h28v07. The data was downloaded from the National Administration and Space Aeronautics (NASA) using the MODISTools package in R\(^1\), and reprojected to WGS84, UTM projection and zone 48 (MODIS reprojection tool version 4.01).

The high resolution colour satellite images were accessed through Google Earth for two periods, 2006 and 2012, and were used for two purposes: to generate random samples, and to visualise and interpret the results of the BFAST analysis. We also used monthly average rainfall and temperature data (2001-2012) from the Lao Meteorology and Hydrology Department, Ministry of Agriculture-Forestry, published by the Lao National Statistical Centre. The data was recorded at the Pakse meteorological station, in the centre of the Champasack Province.

### 2.3 Analysis

#### 2.3.1 Processing Flow

Figure 2 provides an overview of the processing sequence for the research. The analysis was divided into two components; sample preparation and selection, and sample analysis. The sample preparation and selection included image digitising, selection of random samples and extraction of the EVI time series. The sample analysis included calculating long term averages of EVI, comparing them with average rainfall and temperature, and finally, applying and interpreting the BFAST model. More details are explained in the following sections.

#### 2.3.2 Image Digitising

The 2012 Google Earth image was interpreted and digitised to record the distribution of dominant land cover types over the whole study area. Four different land covers were distinguished and digitised from visual interpretation of the high resolution colour imagery; native forest, plantations, mixed wooded/cleared areas and agriculture (Figure 3).

#### 2.3.3 Random Sample Selection

Samples were randomly generated within the land use/cover polygons digitised from the Google Earth 2012 imagery. To ensure that the samples represented single homogeneous land covers, only MODIS pixels falling completely within the digitised cover class polygons were used. The samples were defined by the central point of the 250 x 250 m grid cells corresponding to MODIS pixels, and were at least 500 m from each other. In total, 1,000 random samples comprising of 250 samples for each land cover were generated using ArcGIS.

#### 2.3.4 MODIS EVI Time Series Extraction

These 1,000 random samples were used to extract the MODIS EVI time series from the 2001-2012 records. The resulting MODIS series comprised of 276 16-day EVI composites. A script in R was developed to extract these datasets using the `raster`\(^2\) and `rgdal`\(^3\) packages.

\(^1\)http://cran.fhcre.org/web/packages/MODISTools/index.html  
\(^2\)http://cran.r-project.org/web/packages/raster/index.html  
\(^3\)http://cran.r-project.org/web/packages/rgdal/index.html
2.3.5 Data Analysis

Firstly, we examined the characteristics and seasonal patterns of vegetation within the four dominant land cover types by calculating their long term average EVI from 2001 to 2012 using the 250 random samples for each land cover. We investigated the relationship between the seasonal vegetation responses and climatic conditions by comparing the EVI response to monthly average precipitation and temperature. Secondly, we applied the BFAST algorithm to detect temporal changes in these tropical land covers. BFAST analysis was applied to the average EVI time series derived from the 250 samples for each land cover class. The BFAST algorithm decomposes input time series datasets into three components; trend, seasonal and remainder components (Verbesselt et al., 2010; Verbesselt et al., 2012). Its formula is as follows:

\[ Y_t = T_t + S_t + e_t \]  

(2)

where \( Y_t \) is the observed data at time \( t \), and \( T_t, S_t \) and \( e_t \) are the trend, seasonal, and remainder or residual components respectively. The results of the BFAST analysis were visualised and interpreted against two dates of high resolution imagery from Google Earth (2006 and 2012).
3. RESULTS AND DISCUSSION

3.1 Seasonal Patterns of Vegetation

The four land cover types had distinctly different seasonal patterns of vegetation response as shown by the average MODIS EVI (Figure 4(a)). Native forest had the highest overall EVI with the least variation throughout the year, but a minor peak in July and then slightly higher EVI maintained through to December. Plantations also had high overall EVI, but with greater seasonal variation. Their EVI was lower than that of the native forest for January-June, but higher for August-November. Mixed wooded/cleared areas showed even greater intra-annual range of EVI. It was much lower than forest and plantations for January-July, but with similarly high EVI in the latter half of the year. Both plantations and mixed wooded/cleared areas showed evidence of two peaks in EVI in August and October. By contrast, agricultural land had overall lower EVI, but with greater variation between seasons. Its EVI reached a maximum in September-November.
The EVI dynamics exhibited systematic differences based on vegetation cover, species and management practices in the four land cover types. For example, high canopy cover was maintained throughout the year for forests and plantations. In contrast, the single-species plantations showed more seasonal variation than forest. In mixed wooded/cleared areas, more deciduous trees and shrubs were prevalent, resulting in a pronounced seasonal contrast in EVI. Agricultural areas displayed a distinct annual cycle of land clearance/preparation (January-April), followed by crop planting and growing (June-October), and harvesting (November-December). During the land preparation, there was greater soil exposure, resulting in relatively low EVI. However, it gradually increased during growth of the crops (predominantly rice) and reached a maximum in October.
3.2 EVI Responses to Monthly Precipitation and Temperature

Rainfall and temperature are the crucial drivers of vegetation growth in our study area. There is clear evidence that intra-annual variations of average EVI are strongly influenced by seasonal rainfall. The annual vegetation growth cycles for all vegetation/land cover types closely followed the precipitation pattern with a lag of two to three months when temperature also reduced. From January to April, average rainfall was less than 250 mm (Figure 4(b)), while average temperatures climbed from a low of 26 °C in January to the annual high of 31 °C in April (Figure 4(c)). During this period, vegetation cover or photosynthesis was lower, resulting in lower EVI for all land uses. However, when rainfall increased from late May to September (300-400 mm), the greenness of vegetation started to increase and peaked in October, two months after the July peak of rainfall. This EVI signal still remained high almost for almost two-three months after the end of the rainfall, and then gradually declined in November-December. This is possibly due to persistence of soil moisture and its availability to the deep-rooted perennial trees and shrubs of the forests, plantations, and wooded/cleared areas during this period.

Temperature also seemed to directly influence EVI. Figure 4(c) shows an inverse relationship between monthly average temperature and EVI within all four land-use covers. The minimum EVI coincided with higher temperatures in the dry period (March-April), while the different vegetation types showed more active growth during the mid-range temperatures in June-November. From this figure, it is clear that vegetation growth in this region is strongest during the rainy season (June-November) because of the relatively suitable temperature (26-28°C) and availability of soil water after the period of peak rainfall.

3.3 Detecting Temporal Changes of Vegetation with the BFAST Model

Figure 5 shows the time series of mean EVI (250 samples) for each of the four different land covers analysed by the BFAST algorithm. The trend component of the analysis indicates gradual and abrupt changes in relation to the average EVI for the four land cover types. EVI in native forests remained stable from 2001 to 2010, but there was an abrupt decrease in its response in 2011, after which it increased slightly (Figure 5(a)). More temporal changes were detected across plantation areas. The BFAST trend component suggests that clearing for plantations commenced from the beginning of 2004 to late 2007, followed by maturation and increase in plantation canopies from 2008 until 2011. Their EVI dropped in early 2012 and then continued to increase (Figure 5(b)). The overall trend of vegetation in mixed wooded/cleared areas was downward, with two abrupt changes detected in early 2005 and 2010 (Figure 5(c)). Figure 5(d) shows an overall gradual downward trend of vegetation in agriculture areas.

The temporal changes in these land covers are illustrated by examples from within the study area through comparison of high resolution images from Google Earth for 2006 and 2012. As shown in Figure 6(a), native forests had dense, almost continuous canopy in the 2006 image, with little evidence of disturbance. However, more disturbances were observed in 2012 (Figure 6(b)). BFAST indicated that EVI dropped from 2004 to 2007 and land clearance for plantations is clearly shown in the 2012 high resolution image. This activity is illustrated in Figures 6(c) and 6(d), where land preparation and early-growth plantations were seen in 2006, developing into mature plantations in 2012. The expansion of clearance from 2006 to 2012 was also seen in mixed wooded/cleared areas (Figures 6(e) and 6(f)). However, only agricultural lands showed no change in both images (Figures 6(g) and 6(h)). The EVI trend in this area was steadily downward, suggesting a possible decrease in agricultural production or a change of crop types.

These results show that BFAST was capable of detecting abrupt changes in vegetation dynamics in the land covers in this tropical region and that some of these changes were related to forest clearance and land use change. The most notable changes in the study area were clearance of native forests and conversion of large areas of mixed wooded/cleared areas to plantations.
4. CONCLUSION

This study aimed to investigate the seasonality of vegetation response and to detect temporal changes in tropical land covers across the study area in southern Lao PDR, using the enhanced vegetation index time series data of MODIS. Firstly, the intra-annual responses of vegetation of different land covers were investigated to provide an understanding of typical seasonal patterns. Secondly, BFAST was applied to examine inter-annual changes in vegetation responses over the 2001-2012 period. It was found that average EVI distinguished the annual seasonal growth and characteristic phenological patterns of four different land covers; native forest, plantations, agriculture and mixed wooded/cleared areas. In general, maximum vegetation growth occurred two months after the peak of annual precipitation, coinciding with mid-range monthly temperatures. This suggests that typical seasonal patterns of vegetation growth were primarily determined by water availability and temperature. The BFAST analysis revealed an overall trend since 2001 of decreasing cover or area in native forests and mixed wooded/cleared areas, while plantations increased. Independent evidence derived from Google Earth image interpretation demonstrated that the BFAST analysis of the MODIS EVI time series was capable of detecting areas of known clearances in native forests and their replacement by plantations of perennial trees. Thus, it can be concluded that BFAST analysis of MODIS EVI is a promising tool for assessing tropical land cover type changes.

ACKNOWLEDGEMENT

This study was supported by the Australian Agency for International Development (AusAID) and University of Adelaide. Acknowledgements are given to the National Aeronautics and Space Administration (NASA), Google Earth and Lao National Statistical Centre for providing freely available satellite images and data which were used for this research.
Figure 6: An illustration of examples of spatial changes from Google Earth imagery in 2006 and 2012: (a, b) Native forest (c, d) Plantations (e, f) Mixed wooded/cleared areas (g, h) Agriculture.
REFERENCES


ABSTRACT

Long droughts experienced in Indonesia in the past are identified as one of the main factors in the failure of rice production. In this regard, special attention to monitor the condition is encouraged to reduce the damage. Currently, various satellite data and approaches can provide valuable information for monitoring and anticipating drought hazards. Two types of droughts, meteorology and agriculture, have been assessed. During the last 10 years, daily and monthly rainfall data was derived from TRMM and GSMaP. MTSAT and AMSR-E data was analyzed to identify meteorological drought. Agricultural drought was studied by observing the character of some indices (EVI, VCI, VHI, LST, and NDVI) of 16-day and monthly MODIS data for a period of 5 years (2009 – 2013). A network for data transfer was built between LAPAN (data provider), ICALRD (implementer) and IAARD Cloud Computing, and University of Tokyo (technical supporter). A web-GIS based Drought Monitoring Information System was developed to disseminate the information to end users. This paper describes the implementation of the remote sensing drought monitoring model, and the development of the Web-GIS and satellite based information system.

Keywords: Drought monitoring; satellite remote sensing; meteorological and agriculture droughts; web-GIS; information system.

1. INTRODUCTION

In Indonesia, droughts have occurred more frequently in recent years, which usually disrupt rice production. Sufficient data and information is very important to anticipate this situation and would be strategic for agricultural development policy decisions. Agricultural monitoring techniques to determine land surface information in near real-time is needed and further analysis of data can be used in the current agricultural development planning.

Remote sensing has the ability to provide spatial information which can cover wide areas and record multi-temporal information to help anticipate drought conditions. Remote sensing has proven to be useful for large-area vegetation monitoring given the synoptic coverage, high temporal repeat cycle, continuity and moderate resolution observation of satellite-based sensors. In particular, normalized difference vegetation index (NDVI) time-series data from the Moderate Resolution Imaging Spectroradiometer (MODIS) and National Oceanic and Atmospheric Administration - Advanced Very-High-Resolution Radiometer (NOAA-AVHRR) have been widely used for vegetation and ecosystem monitoring (Tucker et al., 1985; Reed et al., 1994; Jakubauskas et al., 2002). Analysis of
NDVI time-series data and NDVI-derived metrics have been an effective means in identifying vegetation condition anomalies (e.g., apparent declines in vegetation health). Operational efforts, such as the U.S. Drought Monitor (Artusa, 2012), National Drought Mitigation Center (2013) and NOAA's National Weather Service (2013), provide NDVI-derived products that describe the percentage or deviation of current vegetation conditions from the normal conditions, which are expressed historically in the NDVI data. The vegetation condition index (VCI) (Kogan, 1990), which is based on AVHRR's NDVI data, and temperature condition index (TCI), calculated from AVHRR's thermal data (Takeuchi and Gonzalez, 2009), are operationally produced and commonly used for national- to global-scale drought monitoring (Kogan, 1990; Liu & Kogan, 1996; Unganai & Kogan, 1998). Although these numerous operational products have been useful for vegetation monitoring, they are limited for effectively characterizing the impact of drought on vegetation because the anomalies caused by drought stress cannot be discriminated from anomalies produced by other environmental causes of vegetation stress (e.g., flooding, fire, pest infestation and hail damage) and anthropogenic drivers (e.g., land cover/land use conversion). Additional information is required to discriminate the drought-impacted areas from locations where the vegetation is being influenced by these other environmental and anthropogenic factors (Brian et al., 2010).

Traditionally, climate-based drought indicators such as the Palmer drought severity index (PDSI) and standardized precipitation index (SPI) have been used for drought monitoring. However, climate-based drought monitoring approaches have limited spatial precision at which drought patterns can be mapped since the indices are calculated from point-based meteorological measurements collected at weather station locations (Palmer, 1965; Guttman, 1998). In addition, weather stations are scarce in remote areas and they are not uniformly distributed. As a result, climate-based drought index maps depict broad-scale drought patterns that are produced from point-based data using statistical-based spatial interpolation techniques, with the level of spatial detail in those patterns being highly dependent on the density and distribution of weather stations. Therefore, the spatial detail in climate-based drought index maps is limited due to the dependence on uneven and sparse weather station distributions, which limits drought planning and monitoring activities in areas not well covered by weather stations (Brian et al., 2010).

This study is aimed at assessing the use of satellite data to monitor drought conditions in paddy fields in near real-time, validating satellite-based drought models with field observation data, and disseminating the results by developing a web-geographical information system (GIS) that is integrated with an existing crop calendar information system. The results of this study can be used to determine the spatial location of drought areas and its effect on rice production, which will help provide recommendations to prevent future agricultural drought events.

Several methods were used in this to identify drought level, such as SPI and Keetch-Byram drought index (KBDI) for meteorological droughts, and NDVI anomalies, enhanced vegetation index (EVI) anomalies, VCI, TCI, and vegetation health index (VHI) for agricultural droughts. The satellite data used were MODIS, Multifunctional Transport Satellites (MTSAT) and Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E). The analysis showed that these methods can be used to identify the presence of anomalous levels of dryness and drought in the central region of rice production.

2. METHODOLOGY AND DATA USED

Human factors, such as water demand and management can exacerbate the impact that drought has on a region. Due the interplay between a natural drought event and various human factors, drought means different things to different people. In practice, drought is defined in a number of ways that reflect various perspectives and interests (National Climatic Data Center, 2012). Wilhite & Glantz (1985) categorized the definitions in terms of four basic approaches to measuring drought, namely meteorological, hydrological, agricultural and socioeconomic. The first three approaches deal with ways to measure drought as a physical phenomenon. The last approach deal with drought in terms of
supply and demand, tracking the effects of water shortfall as it ripples through socioeconomic systems.

The drought types that were analyzed for this study are meteorological and agriculture droughts, which were based on researches conducted by Takeuchi & Gonzalez (2009), Roswintiati et al. (2010) and Shofiyati et al. (2012). Several methods of meteorological drought index were utilized. KBDI and SPI of the daily and monthly rainfall data from the Tropical Rainfall Measuring Mission (TRMM) and Global Satellite Mapping of Precipitation (GSMaP) were analyzed for several research areas in the last seven years. A five-year time series (2005-2009) of 16-day composite 250 m Terra MODIS data was used to process and analyze agricultural drought by observing some characters of some indices. The data and performance analysis used for this study are presented in Table 1. VHI (Kogan, 1987, 1990) was used to classify agricultural drought, which has five classes (Table 2). The flowchart of the activities conducted in this study is shown in Figure 1.

<table>
<thead>
<tr>
<th>Satellite data</th>
<th>Description</th>
<th>Analysis</th>
<th>Data provider</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODIS</td>
<td>Resolution of 250 m</td>
<td>TCI, VCI, VHI</td>
<td>LAPAN</td>
</tr>
<tr>
<td></td>
<td>(16-day composite)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MTSAT</td>
<td>Resolution of 4 km</td>
<td>KBDI</td>
<td>University of Tokyo</td>
</tr>
<tr>
<td></td>
<td>(daily)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GSMap</td>
<td>Resolution of 0.1°</td>
<td>Daily rainfall data</td>
<td>University of Tokyo</td>
</tr>
<tr>
<td></td>
<td>(every hour)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Drought classification using VHI.

<table>
<thead>
<tr>
<th>Range of VHI</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VHI &gt; 40</td>
<td>No drought</td>
</tr>
<tr>
<td>30 &gt; VHI ≥ 40</td>
<td>Mild drought</td>
</tr>
<tr>
<td>20 &gt; VHI ≥ 30</td>
<td>Moderate drought</td>
</tr>
<tr>
<td>10 &gt; VHI ≥ 20</td>
<td>Severe drought</td>
</tr>
<tr>
<td>VHI ≤ 10</td>
<td>Extreme drought</td>
</tr>
</tbody>
</table>

Figure 1: Flowchart of activities conducted in this study.
3. RESULTS & DISCUSSION

3.1 Drought Analysis

The results at the district level show that MODIS data of 250 m resolution can produce sufficient information to indicate drought conditions through the analysis of VCI, TCI and VHI. The drought classification for the district of Indramayu, as presented in Figure 2, shows that this spatial resolution is sufficient to determine detailed information on drought conditions at a district level such as this. Based on the rainfall data obtained from GSMaP, in 2009, the lowest amount of rainfall occurred between July to November, and the KBDI analysis indicated drought anomalies. Different conditions occurred in 2010, with rainfall data and KBDI analyses showing that the region did not experience drought.

VHI characterizes vegetation health by combining estimation of moisture (VCI) and thermal (TCI) conditions (NOAA STAR, 2010). KBDI measures the amount of moisture in the top layer of soil, and covering leaves and vegetation (Buchholz & Weidemann, 2000). It considers drought as an index on a scale from 0 to 2,000, based on the moisture content of the soil (Keetch & Byram, 1968). Typical drought anomalies can be indicated by the increasing value of KBDI, as well as the decline value of VHI.

NDVI estimates photosynthetic absorption of radiation over the land surfaces (Mitchell, 2002; Piwowar, 2005), at which it can give a measure of the vegetative cover and display greenness level on the land surface (Lillesand et al., 2008). NDVI showed a number of paddy planting seasons, namely Ngawi District, East Java Province has three planting seasons, and Indramayu District, West Java Province has two planting seasons. Decrease of NDVI values is not directly affected by declining precipitation.

Patterns of KBDI, VHI, NDVI and TCI to precipitation for the study locations are presented in Figure 3. It is observed that a small amount of rainfall shows an increase in KBDI, which can be used as a meteorological drought parameter. However, in both study sites, drought anomalies indicated by KBDI does not necessarily affect the condition of vegetation. This means that the level of drought is not causing damage to rice crop. The VHI pattern is more sensitive to vegetation condition. At both locations, the decrease of VHI values, which indicates drought, is followed by the decrease in the values of NDVI or greenness of vegetation. Similarly, on the opposite condition, drought classification using VHI can be used to identify agricultural drought. In this respect, there is no correlation between KBDI and VHI, and the increasing values of KBDI have no effect on VHI values.
3.2 Verification of Results

Field verification was conducted during the dry season of August-September 2013 in Indramayu (Figure 4) in West Java; DI Yogyakarta and Barito Kuala in South Kalimantan; Ngawi and Pasuruan in East Java; and Maros in South Sulawesi. The results showed that KBDI values of 500-600 obtained from MTSAT data indicated the beginning of meteorological drought in the paddy field. Agricultural drought through VHI analysis of MODIS had a high confidence level with 60% accuracy.

In addition to field verification, several workshops and coordination meetings, such as Focus Group Discussion (FGD) were conducted to enhance the output and to get feedback from end users. These meetings were attended by policy makers and other stakeholders such as farmers’ coordinators, regional institutions’ representatives, extension agents and researchers.
3.3 Dissemination with Web-GIS

The results of the analysis of the level of agricultural drought are presented in printed form of a drought levels distribution map of paddy fields as shown in Figure 5. This is also presented in a web-GIS based information system that can be accessed via internet for the wider community. The information system provides information on interactive and integrated drought condition by using Google’s application programming interface (API).

The Indonesian Information System for Drought Monitoring is a daily and monthly product that provides a general summary of current meteorological and agricultural drought conditions. Multiple drought indicators, including various indices, outlooks, field reports and news accounts, are reviewed and synthesized. In addition, numerous experts from agencies and offices across the country were
consulted and involved to generate the product. The result was the consensus assessment presented on the drought level map. Agricultural drought monitoring is presented in the system as shown in Figure 6. Meteorological drought monitoring and information can be searched at webgms.iis.u-tokyo.ac.jp (Takeuchi, 2013), as shown in Figure 7.

Figure 6: The web-GIS based information system for drought monitoring.

Figure 7: The meteorological drought monitoring information system.
5. CONCLUSION

In respect to the assessment of drought impact on rice production, several findings can be drawn from this study. These are related to the development of models to create a web-GIS and satellite based information system. The study reveals that the data obtained for NDVI and VHI from Terra MODIS with resolution of 250 m, rainfall data from GSMap, and KBDI from AMSR-E can be used to identify the presence of anomalous levels of dryness and drought in rice producing centers. Meanwhile, NDVI, VHI and KBDI can represent rainfall anomalies and also capture the onset of drought. VHI from MODIS and KBDI of MTSAT can be also be used to identify patterns of plants with its index to estimate the results.

The validation that was carried out indicated that: (a) Meteorological drought for KBDI analysis with values ranging from 500 to 600 showed the beginning of drought in paddy field; (b) Agricultural drought by analyzing VHI from 250 m Terra MODIS showed a high confidence level with 60% accuracy.

An interactive and integrated web-GIS based information system using Google’s API was developed to disseminate information on drought condition to the wider community. This is very important in preparing remote sensing based data for decision making processes in the national agricultural development policies.

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REFERENCES


HAZE EVENT MONITORING AND INVESTIGATION IN PENANG ISLAND, MALAYSIA USING A GROUND-BASED BACKSCATTER LIDAR

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ABSTRACT

Between 24 July and 1 August 2013, a haze event struck Penang Island, causing decrease in visibility and increase in air pollution index (API). A ground-based backscatter Lidar, operated at 355 nm, was setup at the roof top of the School of Physics, Universiti Sains Malaysia (USM) to monitor and investigate the haze event. For this work, we studied the daytime variation of the aerosol intensity distribution, planetary boundary layer (PBL) height and aerosol optical depth (AOD) values during these days. We found that the aerosols were very intense during the first two days of the haze event and slowly declined as time passed. Finally, the haze event died off on 1 August 2013. As for daily aerosol distribution, the aerosols were generally more intense in the afternoon, and slightly lower in the morning and evening. Similar trends were observed for AOD values as they increased from morning to afternoon and slowly decreased in the evening. Most of the aerosols were found to be contained below the PBL, which was generally found at around 1,000-2,000 m in height.

Keywords: Haze; ground-based backscatter Lidar; aerosol optical depth (AOD); planetary boundary layer (PBL) height; aerosol extinction coefficient.

1. INTRODUCTION

During the past 20-30 years, haze events caused by transboundary biomass burning smoke increased significantly in the Southeast Asia region. Haze events occur recurrently every year during the dry season, typically around June to September. This biomass burning smoke usually comes from forest clearance using fire which goes rampant and develops into uncontrollably burning wild-fires (Salinas et al., 2013). The smoke is then transported by the southwest monsoon across the boundary into other countries.

In June 2013, a serious haze event struck Peninsular Malaysia. The air pollution index (API) reported by the Department of Environment Malaysia (DoE) rose rapidly, and reached unhealthy and very unhealthy levels within a few days, especially in the central and southern parts of Peninsular Malaysia. It is worth mentioning that Muar, a city in the south of Peninsular Malaysia had an API reading on 23 June 2013 that even exceeded 700, which is categorised in the hazardous level according to the DoE official web site (http://apims.doc.gov.my/apims). However, the northern part of Peninsular Malaysia, such as Penang, was less affected by the haze. The API readings were generally maintained at the healthy level until mid-June. After that, the API readings in Penang Island started to fluctuate around the healthy, moderate and unhealthy levels. Generally, haze was found in the atmosphere when the API readings hiked up to moderate and unhealthy level. This situation continued until the end of August.

Haze events are generally highlighted by high concentrations of aerosols suspended in the air. A collection of particles, either solid and/or liquid suspended in a gas is the simplest form of aerosol. Many daily events, such as smoke, smog, fume, dust, haze, fog, mist and cloud, are considered as aerosol (Hinds, 1999). In terms of radiative forcing of Earth’s climate, aerosols affect the Earth’s radiation balance directly by absorbing and scattering incoming and outgoing radiation, depending on the aerosols’ chemical composition. Indirectly, the aerosols act as cloud condensation nuclei (CCN)
and hence, alter the concentration of initial droplets, albedo, precipitation formation and lifetime of the clouds. Aerosols may come from both natural sources, such as volcanoes, sea salts, storms and airborne dust, as well as anthropogenic sources, such as fossil fuels combustion, biomass burning and gas-to-particle conversion process (Balis et al., 2000; Landulfo et al., 2003; Georgoussis et al., 2006; Chen et al., 2009). Aerosols generally show high spatial and temporal variation, depending on the emission and dispersion processes, chemical evolution, as well as meteorological process. Hence, high spatial and temporal resolution measurements, such as Lidar, are very useful in air quality research (Zhang et al., 2012).

Recently, more research has been carried out using Lidar to study the atmosphere. For example, Tsaknakis et al., (2011) used Lidar and ceilometers to obtain aerosol and planetary boundary layer (PBL) profiles over Athens, Greece. A good agreement with the results was obtained from both instruments. Next, Cao et al., (2012) employed two micro-pulse Lidars to study the properties of atmospheric aerosol vertical distribution in Lanzhou, China. The aerosols were found to be distributed quite evenly in the lowermost 2 km of atmosphere. Then, their concentration gradually decreased with increasing height. Lidar is also one of the popular instruments to study dust transportation in many areas around the world. In Greece, Lidar was used to study the Saharan dust layer over Athens (Papayannis et al., 2009); while on the other side of the globe, a group of researchers did a case study on dust aerosol radiative properties in Lanzhou, China (Zhang et al., 2010).

Since the 2013 haze event in Malaysia can generally consider as a recurring event, it is thoroughly important to study and obtain data which can help further understand the aerosol emission and dispersion, as well as its effect on regional and global climatology. The main objective of this study is to monitor the life of the haze event and investigate it using parameters, such as aerosol backscatter coefficients, AOD and PBL height, obtained from a ground-based elastic backscatter Lidar.

During the operation of the Lidar system, a collimated laser beam was emitted into the atmosphere. Then, the laser beam underwent multiple scattering processes in the atmosphere before returning to the Lidar system. A telescope, set up in biaxial arrangement with respect to the laser emitter, captured the return signal (or so called backscatter signal in Lidar terminology). Due to the high temporal (in terms of s) and spatial (3-15 m) resolution of the Lidar system, it was very useful for visualising the vertical distribution of aerosols as well as the instantaneous PBL structure by using aerosols as passive traces (Balis et al., 2000; Landulfo et al., 2003; Georgoussis et al., 2006; Landulfo et al., 2008). Hence, the Lidar system was used during the haze event to monitor the changes of a few parameters, including aerosol backscatter coefficient ($\beta_{aer}$), aerosol optical depth (AOD) and PBL height.

AOD was chosen as one of the parameters to be monitored because it is a measure of the degree of light extinction by aerosols through absorption or scattering in the atmospheric column (Donkelaar et al., 2010). Light scattering and absorption by aerosols will diminish the solar radiation and limit the visual air quality. Consequently, visibility will be reduced and air quality will decrease (Chen et al., 2009). On the other hand, PBL is the lowermost sub-layer of the troposphere. It is directly affected by the earth and solar radiance, as well as anthropogenic activities on the earth’s surface (Tsaknakis et al., 2011). Moreover, heat and moisture from the earth’s surface must first be well mixed before circulating in the free troposphere. Thus, aerosol concentrations in the PBL are generally higher as compared to that of in the free troposphere (Menut et al., 1999; Tsaknakis et al., 2011). Generally, most aerosols are concentrated in the PBL, as it is in direct contact with the ground. Nearly all aerosol sources come from the ground level (Matthias & Bosenberg, 2002). Hence, PBL height data is vital in atmospheric dynamics studies (Tsaknakis et al., 2011).

2. INSTRUMENTATION

An eye-safe ground-based backscatter Lidar system, model no. LB100-ESS-D200, manufactured by Raymetrics SA, was setup on the roof top of the School of Physics, Universiti Sains Malaysia (USM),
Penang. The location is shown in Figure 1. This elastic backscatter Lidar system is capable of profiling aerosols and clouds by transmitting laser pulses into the atmosphere and measuring the return time of the backscatter signal. It is operated with a neodymium-doped yttrium aluminium garnet (Nd:YAG) pulsed laser that emits a 355 nm laser beam into the atmosphere. The pulse duration is 5.04 ns, with the energy emitted in each pulse being 33.4 mJ with a 20 Hz repetition rate. The returned signal is then collected by a Cassegrain telescope with diameter of 200 mm, 1 mrad field-of-view and complete overlap height of 180 m. The telescope is set up with monostatic configuration and biaxial arrangement with respect to the laser emitter. The captured signal is then spectrally analysed, filtered and focused on a photon multiplier tube (PMT), with a corresponding spatial and temporal resolution of 7.5 m and 1 min respectively. Next, the current generated from the PMT is detected by a Licel transient recorder, and the analogue Lidar signal is obtained and recorded. By using a combination of a powerful analogue-to-digital (A/D) converter (12 bit at 40 MHz) with a 250 MHz fast photon counting system, the photon counting Lidar signal is obtained and recorded.

![Figure 1: Topographic map produced from a global digital elevation model (GDEM) showing the high-mountain and low-plain regions in Penang. The five-edged star is the study site (USM) where the Lidar system was deployed.](image)

3. METHODOLOGY

3.1 Data Acquisition

The Lidar system was set to shoot at the zenith on every weekday except on rainy days or public holidays. The acquisitions started from UTC 0200 to 1000, which corresponds to 1000 to 1800 Malaysian local time. The Lidar system was set to an average of 1,200 shots into a data file, which means that one data file will be produced every min.

3.2 Data Pre-processing

The acquired data was processed using Lidar Analysis, which is the processing software provided by Raymatrics SA. Before starting the data processing, the usage of analogue, photon counting or glued signal had to be determined according to the conditions stated in Tan et al. (2012). Then, the background radiation was subtracted from the Lidar signal. If the photon counting or glued signal was used, dead-time correction had to be further applied as given by Donovan et al. (1993). Next, the range corrected signal (RCS) was obtained by applying the distance square law correction ($z^2$) to each data point to compensate for range-related attenuation from the atmosphere. After that, the temporal evolution of the RCS is plotted. This plot showed the general view of the atmospheric conditions.
Days with strong backscatter signals from the lower atmosphere, typically below 2,000 m, was selected and identified as hazy days. In this case, the hazy days lasted from 24 July to 1 August 2013.

### 3.3 Data Processing

When the pre-processing was completed, the aerosol backscatter coefficient ($\beta_{\text{aer}}$) was calculated with the aid of the Lidar Analysis software. Here, the Klett inversion technique (Klett, 1981) was used to retrieve the aerosol backscatter coefficient. This was done using a simple numerical integration from the reference height until the ground level (inward stepwise integration) since this method is more stable (Fernald, 1984). The reference height is a height where almost no aerosol backscatter signal is found, and the backscatter signal is mostly molecular (Ansmann et al., 1992). To use the Klett inversion technique, an assumption had to be made on the Lidar ratio of the studied aerosol. In this case, the Lidar ratio was assumed to stand at 40 sr and remained constant throughout the haze period. Although a Lidar ratio of 40 sr is slightly lower than the Lidar ratio for Southeast Asian aerosols and biomass burning aerosols, as stated by Cattrall et al. (2005) and Muller et al. (2007), since Penang is a highly urbanised and industrialised city on an island, a certain degree of mixing between marine, Southeast Asian and biomass burning aerosols is expected, causing the Lidar ratio to be lower than the value suggested in the literature. After the aerosol backscatter coefficient was calculated, the temporal evolution of the aerosol backscatter coefficient was plotted.

Next, the hourly PBL height and AOD were calculated. To determine the PBL height, the data files at each hour were selected. The inflection point method (IPM) proposed by Menut et al. (1999) was applied, where the minimum of the second derivative of the RCS gives the PBL height.

In addition, for hourly AOD, the average light extinction effect by aerosols throughout a particular hour, assuming the aerosol loading in the atmosphere does not change very much throughout the hour, was taken into account. Hence, the data files need to be averaged for that particular hour and AOD was calculated as follows:

$$AOD = \int_{R_0}^{R_{\text{max}}} \alpha_{\text{aer}}(r) \, dr$$

(1)

where $R_{\text{max}}$ is the reference height, $R_0$ is the height where the overlap is complete and $\alpha_{\text{aer}}$ is the aerosol extinction coefficient which is given by:

$$\alpha_{\text{aer}} = L_{\text{aer}} \ast \beta_{\text{aer}}$$

(2)

where $L_{\text{aer}}$ is the aerosol Lidar ratio and $\beta_{\text{aer}}$ is the aerosol backscatter coefficient.

### 4. RESULTS AND DISCUSSION

The study period started from 24 July 2013 and ended on 1 August 2013. A total of six daily measurements were made during the study period, while the remaining days fell on weekends and public holidays, where the Lidar system was not operated. These measurements covered the whole life cycle of the haze event, starting from when the haze started to be detected, right until it died off. During these six days, significant differences in the aerosol distribution pattern were found during the haze event as compared to the day when the haze died off. These changes in aerosol distribution pattern change the Earth’s radiative forcing and cloud formation in the atmospheric column, which ultimately affects local and regional climates.

As aerosols are generally contained in the PBL, the first step was to determine the PBL height during the study period. Using the IPM method, the minimum of the second derivative of the RCS provided information on the PBL height. The calculated PBL heights, in m, are shown in Table 1. Generally, the PBL height was below 2,000 m and increased from morning to afternoon. It then slowly decreased
when approaching evening. This means that more aerosols were loaded in the atmosphere in the afternoon as compared to the morning and evening.

**Table 1: PBL height (m) evolution during the study period.**

<table>
<thead>
<tr>
<th>Date/UTC Time</th>
<th>02:00</th>
<th>03:00</th>
<th>04:00</th>
<th>05:00</th>
<th>06:00</th>
<th>07:00</th>
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Figure 2 shows the temporal evolution of the aerosol backscatter coefficient for the study period, with the black colour line indicating the PBL height. The calculated PBL heights were plotted in respective profiles at respective times, while PBL heights at other times are extrapolated. From the profiles, the daytime aerosol distribution pattern and the intensity of the aerosol loading in the atmosphere can be observed. During the study period, aerosols were generally contained under the PBL, except for 30 July 2013, where a residual layer was found above the PBL at around UTC 0200 to 0300. This residual layer had a very low concentration of aerosols, as indicated by the low backscatter coefficient, and was very short lived. Hence, it was suspected that a convection effect was responsible for making the aerosol load higher than the PBL, which slowly descended and mixed together with other aerosols in the PBL. Next, on 24 and 25 July 2013, there was a thick aerosol layer loaded under the PBL. This thick aerosol layer indicated that the amount of aerosol loading in the atmosphere was very high, which was further supported by the high aerosol backscatter coefficient on these two days. This also showed that the haze event was serious on these two days. Then, it was followed by two slightly clearer days on 29 and 30 July 2013, where the aerosol backscatter coefficients were quite low under the PBL. After that, the haze returned again as the amount of aerosol in the atmosphere again increased on 31 July 2013. However, the amount of aerosol loading in the atmosphere on this day was not as high as the first two days since the aerosol backscatter coefficients were not as high as those obtained during the first two days. The aerosol layer was also thinner as compared to the first two days. Finally, on 1 August 2013, only a thin layer of aerosols was found loading in the atmosphere, with low aerosol backscatter coefficient, which indicated that the haze had finally died off.

Moving on to daily aerosol distribution, aerosols were generally distributed under 2,000 m in height, which was bounded by the PBL. Relatively heavily polluted days gave higher PBL heights as compared to the mildly polluted days, as shown in Figure 2. For example, on 24, 25 and 31 July 2013, which were heavily polluted days, the PBL height was generally maintained at around 1,000 to 1,500 m. As for mildly polluted days, the PBL height was maintained at around 500 to 1000 m, as shown in the profiles for 29 and 30 July 2013. Compared to polluted days, a clear day has an even lower PBL height. For example, on 1 August 2013, after the haze died off, the PBL height was generally found at 500 m, which is very close to the Earth’s surface. As for daily aerosol distribution, it is very much dependent on the PBL height. During the study period, most of the aerosols were contained under the PBL, except when there was a residual layer. Hence, the aerosol layer generally increase its height together with the PBL from morning to afternoon and decreased its height together when approaching evening, unless the residual layer existed and caused the aerosol layer load to be higher than the PBL, as shown in the aerosol backscatter profiles for 30 July 2013 from UTC 0200 to 0300.
Figure 2: Temporal evolution of aerosol backscatter coefficients (m\(^{-1}\) sr\(^{-1}\)) on (a) 24, (b) 25, (c) 29, (d) 30 and (e) 31 July, and (f) 1 August 2013. The black colour lines indicate the PBL height.

Figure 3 shows the vertical profiles of the aerosol extinction coefficient. Based on the profiles, the aerosol extinction coefficient was decreasing very fast with increasing height. This proved that there was lesser aerosol with increasing height. It was found that the aerosol extinction coefficient was very low beyond 2,000 m in height, which means that the aerosols were generally contained below 2,000 m in height and only minor aerosols existed beyond that height. This suggests that most of the aerosols were concentrated under the PBL since the PBL height listed in Table 1 did not exceed 2,000 m. As shown in Figure 3, the aerosol extinction coefficient for 25 July 2013 at UTC 0235 was the highest, followed by 24 July 2013 at UTC 0305 and 31 July 2013 at UTC 0305. However, the aerosol extinction coefficient profiles for these times were slightly different. The aerosol extinction coefficient for 25 July 2013 decreased very fast after 500 m in height and dropped even lower after exceeding 1,000 m in height. For 24 July and 31 July 2013, the aerosol extinction coefficient started to drop at around 1,000 m in height and fell to a very low aerosol extinction coefficient value at 2,000 m. This showed that on 24 and 31 July 2013, the aerosol layer had a thickness of around 2,000 m, but for 25 July 2013, the aerosol layer was thinner, where its thickness was just around 1,000 m. Besides that, on 25 July 2013, aerosols were loaded very low at a height of around 700 m, given by the high
aerosol extinction coefficient up to this height. Compared to 25 and 31 July 2013, the aerosols were loaded higher in the atmosphere, up to around 2,000 m in height, given by the relatively high aerosol extinction coefficient value up to this height. However, the light extinction capability of the aerosols on 25 July 2013 was much higher than that of 24 and 31 July 2013, given by the relatively higher aerosol extinction coefficient in the lower atmosphere as compared to the other two days. This suggested that the aerosols may have underwent a characteristics change from 24 to 25 July 2013, or there might be an aerosol intrusion during night time on 24 July 2013, when the Lidar was not operating and the aerosols were completely mixed up with local aerosols by the next morning. On 30 July 2013 at UTC 0220, the aerosol extinction coefficient profiles had two peaks, one at around 500 m in height and the other at around 1,300 m in height. This demonstrates that there were two aerosol layers present during that particular time, which agrees well with what is shown in Figure 2.

![Figure 3: Aerosol extinction coefficient profiles (m⁻¹) for the selected days and times during the study period.](image)

Figure 4 displays the hourly AOD during the study period. Higher AOD generally means that there are more aerosols in the atmosphere, because these aerosols will obstruct the transmission of light either through absorption or scattering processes. However, clouds are also considered as aerosols. Light undergoes a high degree of extinction when passing through clouds, causing an extremely high AOD. In the Southeast Asia region, AOD readings lower than 0.3 usually mean that there are only minor aerosols contained in the atmosphere, while AOD readings higher than that represent polluted air. AOD readings higher than 2.0 are usually caused by cloud contamination. Based on Figure 4, 24 and 25 July were days with highly polluted air, marked by the high AOD readings. Then, 31 July 2013 had moderately polluted air, as given by the lower AOD reading as compared to 24 and 25 July 2013. Next, 29 and 30 July 2013 were days with slightly polluted air, as indicated by the low AOD readings. Finally, 1 August 2013 was the day that the haze died off, as the AOD reading was very low. The hourly AOD distribution also showed a general view on how the aerosols were distributed in the atmosphere. Although the AOD distribution did not show a similar trend over the study period due to difference in aerosol concentration over the study period, relatively high AOD was generally found in the afternoon, and lower AOD was found in the morning and evening, except for highly polluted days, where high amounts of aerosols were loaming around the sky all the time, causing the AOD to remain very high all the time. The AOD distribution trend means that more aerosols are distributed in the
atmosphere during the afternoon as compared to the morning and evening. However, this pattern was similar during hazy days or a clear day. Although the AOD distribution trend might look similar to the PBL height evolution trend, both trends are not identical. This is because AOD is a measure of the degree of light extinction in the atmospheric column by aerosols, and is dependent on the types and composition of aerosol, as well as the age of the aerosol. However, PBL is more affected by heat from the Earth and the sun, as well as anthropogenic activities on the Earth’s surface. Direct heat from the sun in the afternoon together with peak human activity at that time caused the PBL load to be higher at this time than in the morning and evening. Moreover, PBL is just a sublayer in the atmosphere where the aerosol concentration is a few magnitudes higher than that of in the free troposphere, but the aerosols in the free troposphere are not negligible. These aerosols still contribute a significant value to the AOD reading, causing the daily AOD trend to be different from the PBL height evolution trend.

Figure 4: Hourly AOD obtained using Lidar during the study period.

5. CONCLUSION

In this study, a ground-based backscatter Lidar was used to study the haze event in Penang Island from 24 July to 1 August 2013. The PBL was found at a higher height on hazy days as compared to the clear day after the haze died off. Both the temporal evolution of aerosol backscatter coefficients and hourly AOD readings showed that high amount of aerosols were loaded under the PBL during the haze, particularly on 24, 25 and 3 July 2013. These readings also showed that more aerosols were loaded in the atmosphere in the morning and afternoon as compared to the evening, regardless of the atmospheric conditions. On the whole, the results from this study provided important insight on aerosol variation and distribution during a haze event, which is essential for future studies on aerosol emission, growth, transportation and dispersion in the Southeast Asia region. Future studies should involve a synergy of measurements which combine different in situ data, such as particulate meter, sunphotometer, and satellite data, into a more comprehensive result that allows us to study the haze event in details.

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