INTEGRATION OF BATHYMETRIC AND TOPOGRAPHIC DATA FOR PARTIAL ASSESSMENT OF COASTAL VULNERABILITY INDEX IN MALAYSIA

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A thesis submitted in fulfilment of the

Requirements for the award of the degree of

Master of Science (Geomatic Engineering)

Faculty of Geoinformation and Real Estate
Universiti Teknologi Malaysia

OCTOBER 2016

DEDICATION

To my beloved husband Muhammad Ridzuan Ghazali, my beloved daughter Ainaa Insyirah, my parents, my family and my friends.

ACKNOWLEDGEMENT

Alhamdulillah, praise to Allah the Most Gracious and Most Merciful for granted me with useful knowledge, strength and blessing for completing this study. Praise to Allah for listening to my prayer. I wish to expand my gratitude towards my supervisor, Assoc. Prof Kamaludin Mohd Omar and Dr Muhammad Zulkarnain Bin Abd Rahman. Their continuous support, motivation,enthusiasm and immense knowledge assisted me in writing for a good thesis. And I would like to thank to National Hydrographic Centre for the warmest cooperation and assistance during the entire duration of the project in collecting and processing the data. This thesis would not have been possible without the guidance and contributions of several individuals who helped and extended their valuable assistance in the preparation and completion of this project. I am indebted to my beloved family, friends and classmates for their continuous encouragements against all odds. Lastly, I offer my regards to all of those who supported me in any respect during the completion of the project.

ABSTRACT

Coastal area is a dynamic area of interaction between land and water. Seamless coastal mapping allows coastal management authorities to identify the characteristics and the transition process from land to sea. Recently, researchers have developed the Coastal Vulnerability Index (CVI) to determine the vulnerability of coastal areas to coastal hazards such as coastal erosion. Malaysia implemented its pilot project of CVI at Tanjung Piai, Johor and Pulau Langkawi, Kedah in 2007. However, the analysis of CVI parameters was carried out separately and a large scale of coastal mapping has not been carried out yet. There are six physical parameters of CVI, namely shoreline change rate, coastal slope, relative sea-level change, tidal range, geomorphology and mean wave height. In this study, two parameters which are shoreline change rate and coastal slope were analyzed to determine the coastal vulnerability of study area. At present, in Malaysia there is no single technology that can measure both terrain height and water depth to a suitable level of accuracy and density to develop a seamless coastal mapping. LiDAR (Light Detection and Ranging) technology has the ability for measuring terrain heights, but, it does not have the ability to penetrate water to yield bathymetric result. In this study, the bathymetry data and LiDAR data were integrated to develop a seamless coastal mapping by standardizing the vertical datum and the coordinate system. Additional information of water level was added into coastal mapping to delineate the shoreline positions and to determine the shoreline change rate. The results show that the area of Minyak Beku, Batu Pahat, Johor is located at low lying region and eroded at a magnitude of more than 6m per year. In conclusion, integration of bathymetric and topographic data could generate a seamless coastal mapping as a support for CVI analysis.

ABSTRAK

Kawasan persisiran pantai merupakan kawasan dinamik bagi interaksi antara kawasan laut dan darat. Pemetaan pantai yang berterusan membolehkan pihak pengurusan pantai untuk mengenalpasti ciri-ciri dan proses peralihan dari darat ke laut. Baru-baru ini, para penyelidik telah membangunkan indeks kerentanan pantai (CVI) bagi menentukan kelemahan kawasan pantai terhadap ancaman bencana pantai seperti hakisan pantai. Malaysia telah melaksanakan projek perintis CVI di Tanjung Piai, Johor dan Pulau Langkawi, Kedah pada tahun 2007. Walau bagaimanapun, analisis berdasarkan pemboleh ubah CVI telah dijalankan secara berasingan dan pemetaan pantai berskala besar belum lagi dilaksanakan. Terdapat enam pemboleh ubah fizikal CVI yang digunakan untuk membangunkan CVI iaitu kadar perubahan garis pantai, cerun pantai, perubahan aras laut relatif, julat pasang surut, geomorfologi dan purata ketinggian ombak. Dalam kajian ini, dua pemboleh ubah CVI di analisis iaitu kadar perubahan garis pantai dan cerun pantai bagi mengenal pasti tahap kerentanan pantai bagi kawasan kajian. Pada masa ini, di Malaysia tiada teknologi tunggal yang membolehkan pengukuran ketinggian rupa bumi dan kedalaman air dengan tahap kepadatan dan ketepatan yang sesuai bagi melaksanakan pemetaan pantai yang berterusan. Teknologi pengukuran penderiaan cahaya dan jarak (lidar) mempunyai keupayaan untuk mengukur ketinggian muka bumi, tetapi tidak berupaya untuk menembusi air bagi mendapatkan maklumat kedalaman. Dalam kajian ini, data batimetri dan data lidar telah diintegrasi bagi membangunkan pemetaan kawasan pantai yang berterusan dari darat ke laut dengan melakukan penyeragaman datum tegak dan sistem koordinat. Maklumat tambahan aras laut turut digunakan dalam pemetaan pantai bagi menggariskan kedudukan garis pantai dan menentukan kadar perubahan garis pantai. Hasil kajian mendapati kawasan kajian di Minyak Beku, Batu Pahat, Johor terletak di kawasan rendah dan terhakis pada magnitud lebih daripada 6m setahun. Kesimpulannya, integrasi data batimetri dan topografi mampu menjana pemetaan pantai berterusan dan menjadi sokongan untuk analisis CVI.

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LIST OF ABBREVIATIONS

CVI	-	Coastal Vulnerability Index
DEM	-	Digital Elevation Model
DID	-	Department of Drainage Malaysia
GPS	-	Global Positioning System
GCP	-	Ground Control Point
HWL	-	High Water Line
HAT	-	Highest Astronomical Tide
IPCC	-	Intergovernmental Panel on Climate Change
ISMP		Integrated Shoreline Mapping Programme
JUPEM	-	Departments of Surveying and Mapping Malaysia
JPSM		Jabatan Perhutanan Semenanjung Malaysia
MHW	-	Mean High Water
MHWS		Mean High Water Spring
MHWN	-	Mean High Water Neap
MLLW	-	Mean Lower Low Water
MLWS	-	Mean Low Water Spring
MLWN	-	Mean Low Water Neap
MSL	-	Mean Sea Level
NCVI		National Coastal Vulnerability Index
NCES		National Coastal Erosion Study
NGVD	-	National Geodetic Vertical Datum
NHC	-	National Hydrographic Centre

RTK	-	Real Time Kinematic
RSO	-	Rectified Skew Orthomorphic
SAR		Syntetic Aperture Radar
USGS		United States Geological Survey
UNEP		United Nations Environmental Programme

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The Coastal Vulnerability Index (CVI) is one of the coastal management plans by indexing the coastal area in response to future sea level rise. Malaysia has implemented its pilot project of CVI in Tanjung Piai and Pulau Langkawi to evaluate its physical change along coastal area in response to the rising of sea-level (DID, 2012a). There are six variables in physical CVI, which are geomorphology, coastal slope, rate of relative sea-level rise, rate of shoreline change erosion or accretion, mean tide range and mean significant wave height (Klose and Theiler, 2001). This research were focusing on the geologic variables which are historical shoreline change rate and coastal slope which account for shoreline erosion and accretion trend, shoreline resistance to erosion and its susceptibility to flooding (Pendelton *et al.,* 2004). By developing a seamless topography and bathymetry at coastal areas this information can be easily extracted from coastal mapping. The topographic and bathymetric data can be integrated by applying a vertical datum conversion for land surveys and traditional hydrographic survey (Wozencraft, 2000). In addition, transforming surveyed elevations and water depths to desired vertical datums is an essential step in building a regional coastal management plan.

According to the Department of Drainage Malaysia (DID, 2012a), the definition of coastal area includes 5km landwards and 16.1 nautical miles onshore from neap tides. It is a transition from onshore to offshore which involves two different datum that are from land and water areas. The authority of mapping land area is by Departments of Surveying and Mapping Malaysia (DSMM) or Jabatan Ukur dan Pemetaan Malaysia (JUPEM). They are responsible in driving the development of the country and serves as a government adviser in the field of surveying and mapping as well as executing surveying and mapping as a basis for socio-economic development and national sovereignty. While for maritime, National Hydrographic Centre is a qualified agency which is responsible in implementing hydrographic surveying and mapping in Malaysia. Topographic map and Nautical Chart are not seamless since it involves different types of datum. Hence, the vertical datum conversions between both data to a common vertical datum are required to perform standard definition of shorelines and to merge these data for coastal analysis.

Coastal mapping is a seamless combination of topography and bathymetry; however the realization of constant elevation from onshore to offshore data is difficult since it needs to deal with problems such as difference in scale, resolution, cartographic convention and projection, and particularly reference datum inherently inhibits the seamless combination of existing onshore and offshore data. The seamless coastal mapping enables the coastal community to understand natural processes that occur across shoreline area such as to study coastal changes. There are a few aspects that has been highlighted by coastal community according to their needs in coastal mapping such as a consistent a spatial framework for coastal data that allows a seamless transition from onshore to offshore, a standard definition of shorelines and compatibility among data formats or standards and transformation protocols that allows easy data exchange (National Academy of Sciences, 2005).

In this study, a shoreline definition from both topography and bathymetry data were identified to produce a set of constant reference datum for land-water interface. The vertical datum from onshore and offshore will be converted to common datum which conforms to datum specifications for each data. As a result, a coastal mapping of selected area is produced and can be a subset for coastal vulnerability index (CVI). The information of shoreline and coastal slope were extracted from the coastal mapping for coastal analysis.

1.2 Statement of Problem

Coastal area is a dynamic change area comprises of intertidal zone plus a few kilometres landwards and a few kilometres seawards from shoreline (Reilly *et al.*, 2003). As it is an area of interaction between land and water area, indirect factors from land and water area can influence the stability of coastal area. Previous study shows that the study on intertidal zone is done separately and leads to redundancy of data collection for the same area (Reilly *et al.*, 2003; DID, 2012a; DID, 2012b).

To identify the characteristics and physical changes of coastal area, a standard vertical datum reference for both areas is a basis in mapping. In Malaysia, the vertical datum for land area is based on mean sea level value from Port Kelang while for sea area; Lowest Astronomical Tides are used as a chart datum. The main problem when using multiple datum; it will lead to the discontinuity between land region (datum B) and water region (datum A). The latitude, longitude and height in datum A are certainly different with latitude, longitude and height in datum B (Figure 1.1). Hence, the spatial relationship between the data could not been identified.

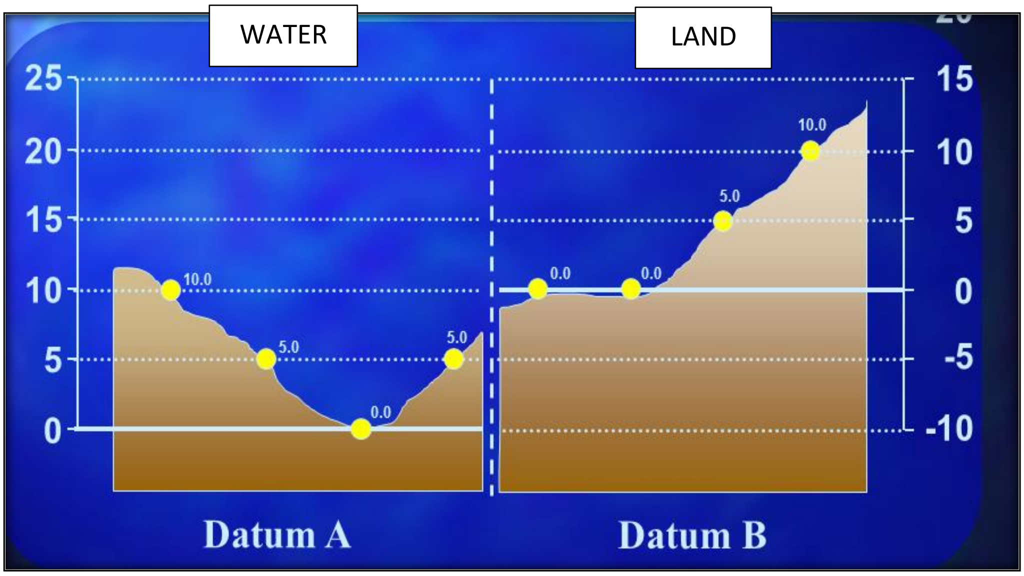

Figure 1.1 Discontinuity between datum A and datum B (Milbert, (2002))

In this study, the elevation value from LiDAR DEM and depth of sea area were merged to a common datum to test the capability and reliability to develop a seamless boundary of land and water area and for a seamless coastal mapping. Perhaps the resolution fine enough to describe the small variation in that area and can provides relevant elements for CVI such as shoreline change rate and the steepness of the coastal slope.

Furthermore, the definition of shoreline itself is numerous. Consistencies in referring shoreline definition for both areas are important so that they are referring the same shoreline indicator for coastal analysis. Shoreline definition often has a high level of uncertainty since there is natural inconsistency to deal with and because it often deals with different process and techniques for delineation processes.

1.3. Aim of Study

The aim of this study is to integrate topographic and bathymetric data, in order to generate a coastal mapping as a support for coastal vulnerability index (CVI) information.

1.3.1 Objectives of Study

The aim of this study is supported by several objectives as follows:

a) To develop a method to integrate bathymetry and topography data as a seamless coastal mapping.
b) To evaluate shoreline positions during 1988,2009, and 2014.
c) To estimate the steepness of coastal slope by using the integrated data.

1.3.2 Research Question

Research question is important to achieve the objectives of the study. Table 1.1 describes the research questions used in this study.

Table 1.1: Research question

No.	Objectives of Study	Research Questions
1	To develop a method to integrate bathymetry and topography data as a seamless coastal mapping.	a) How to merge different datum from land and water area? b) How to transform elevation and depth data to desired datum? c) What are the best interpolation methods for LiDAR and bathymetry data?
2	To evaluate shoreline positions during 1988, 2009, and 2014.	a) What are the best indicators that represent shoreline for both datum? b) What is the trend of shoreline change for each area? c) How to delineate shoreline from different sources?
3	To estimate the steepness of coastal slope by using the integrated data.	a) How to measure coastal slope in coastal area? b) How to identify the possible area which tends to gain land due to accretion or loss of land due to erosion?

1.4 Scope of the Study

This study aims to integrate the bathymetry and LiDAR data at Minyak Beku to develop a seamless coastal mapping to support CVI information. Bathymetry data were provided from National Hydrographic Centre (NHC), while the LiDAR data was provided from MK Surveys.

1.4.1 Coastal Vulnerability Index Parameters

CVI is an index-based approach to quantify vulnerability in coastal regions. The CVI method yields numerical data that cannot be linked directly with particular physical effects but it highlights those coastal segments where the effects of sea-level rise might be the greatest, for example, where there is the greatest chance that physical changes will occur as sea-level rise (Mahapatra *et al.*, 2013).

The effects of sea level rise, on the other hand, have a vital relationship with four variables of CVI, which are coastal slope, shoreline erosion, tidal range, and mean significant wave height. The effects of sea level rise are exhibited in shoreline erosion which will be large on low sloping coastal regions, thus allowing storm waves (from storm surges) to be able to cause damages further in land (Dwarakish *et al*., 2009). Due to limitations of data and time constraints, this study was focusing on physical variables of CVI. However, only two elements were selected which are shoreline change rate and coastal slope (%). It is because, coastal slope highlights the most affected areas in terms of the potentiality of inundation and rapidity of shoreline retreat as steeper coastal regions retreat slower than low-sloping coastal regions due to shallow water is exposed to high wave energy (high wave height) (Gill *et al.,* 2014). This study adopted Klose and Thieler methodology to evaluate the value of coastal slope and shoreline change rate. This is carried out through an index-based approach by assigning each variable to numerical values ranging from 1 to 5, where 1 is the lowest risk of coastal vulnerability and 5 is the highest risk (Table 1.2).

Once each variable has been assigned a vulnerability value, the CVI is calculated as the square root of the ranked variables divided by the total number of variables (Gornitz *et. al.*, 1994).

$$CVI = \sqrt{\frac{a \times b \times c \times d \times e \times f}{6}} \qquad \text{Equation 1.1}$$

Where a is a geomorphology, b is a shoreline erosion rate (m/yr), c is a coastal slope(%), d is a mean significant wave height (m), e is a mean tidal range (m), and f is a relative sea level rate (mm/yr).

Malaysia has adopted United States Geological Survey (USGS) methodology to compute the CVI for Physical Vulnerability Index, South Pacific Applied Geo-science Commission for the Biological/Environmental Vulnerability Index, and United Nations Environmental Programme (UNEP) Handbook Methodology for the Total of Composite Vulnerability Index which includes socio-economic variables. According to USGS (2004), the CVI presented in USGS methodology is the same as that used in Klose and Thieler (2001) and is similar to that used in Gornitz *et al.*, (1994). Hence, it indicates that USGS methodology and Thieler and Klose methodology (2001) is the same. NCVI includes biological, socio-economic and physical variables to compute CVI. However, in this study only two variables of physical CVI which are shoreline change rate and coastal slope were extracted.

Table 1.2: Ranking of CVI (Klose and Thieler, 2001)

Ranking of Coastal Vulnerability Index					
Variable	Very Low	Low	Moderate	High	Very High
Geomorphology	Rocky, cliffed coasts, Fiords, Fiards	Medium cliffs, Indented coasts	Low cliffs, Glacial drift, Alluvial plains	Cobble beaches, Estuary, Lagoon	Barrier beaches, Sand beaches, Salt marsh, Mud flats, Deltas, Mangroves, Coral reefs
Coastal Slope (%)	>0.115	0.115-0.055	0.055-0.035	0.035-0.022	<0.022
Relative sea-level change (mm/yr)	<1.8	1.8-2.5	2.5-3.0	3.0-3.4	>3.4
Shoreline erosion/accretion (m/yr)	>2.0	1.0-2.0	-1.0-+1.0	-1.1- (-2.0)	<-2.0
	Accretion		Stable	Erosion	
Mean tide range (m)	>6.0	4.1-6.0	2.0-4.0	1.0-1.9	<1.0
Mean wave height (m)	<0.55	0.55-0.85	0.85-1.05	1.05-1.25	>1.25

1.4.2 Study Area

The southwest coastal region of west Johor, peninsular Malaysia is composed primarily of unconsolidated sediments, clay and silt, located at the low lying region, except for the granite hill in Batu Pahat. As a result, low lying region causes a poor drainage while the coastline stability can be influenced by the sediment transport budget. The location of Batu Pahat which is located along the coastal of Malacca Strait is an economically growing area and it has developed as a tourist destination. However, these areas have been affected by a serious problem of erosion along the coast of Malacca Straits. Those phenomena had caused destructions to infrastructures such as fisheries, tourist and facilities near the shore.

According to Integrated Shoreline Mapping Programme (ISMP) report by DID (2012b), numerous location of coastlines were identified to determine the extent of erosion and accretion. These locations were chosen because of the significance changes in shoreline movement. Figure 1.2 shows the location of shoreline changes from Muar to Pontian using topographic map from 1974 as baseline reference and satellite images from 2010. Point 20 to 28 in Figure 1.2 shows the location of shoreline changes at Batu Pahat. The results of shoreline change analysis are shown in Table 1.3. From the results, it indicates that the area of Batu Pahat facing a serious problem of erosion.

Table 1.3: Shoreline change analysis at Batu Pahat (DID, 2012b)

Point	**Location**	**Total coastline changes (m) (Years 1974-2010)**	**Annual changes per year (m/y)**
20	Sungai Tongkang	-287.0	-8.0
21	Sungai Punggor	-218.9	-6.1
22	Sungai senggarang	-177.7	-4.9
23	Sungai Koris	-244.3	-6.8
24	Sungai suloh Besar	-288.4	-8.0
25	Tanjung Segenting	609.0	16.9
26	Tanjung Api-api	130.2	3.6
27	Parit Kuda (Northern Bank)	204.1	5.7
28	Parit Kuda (Southern Bank)	183.7	5.1

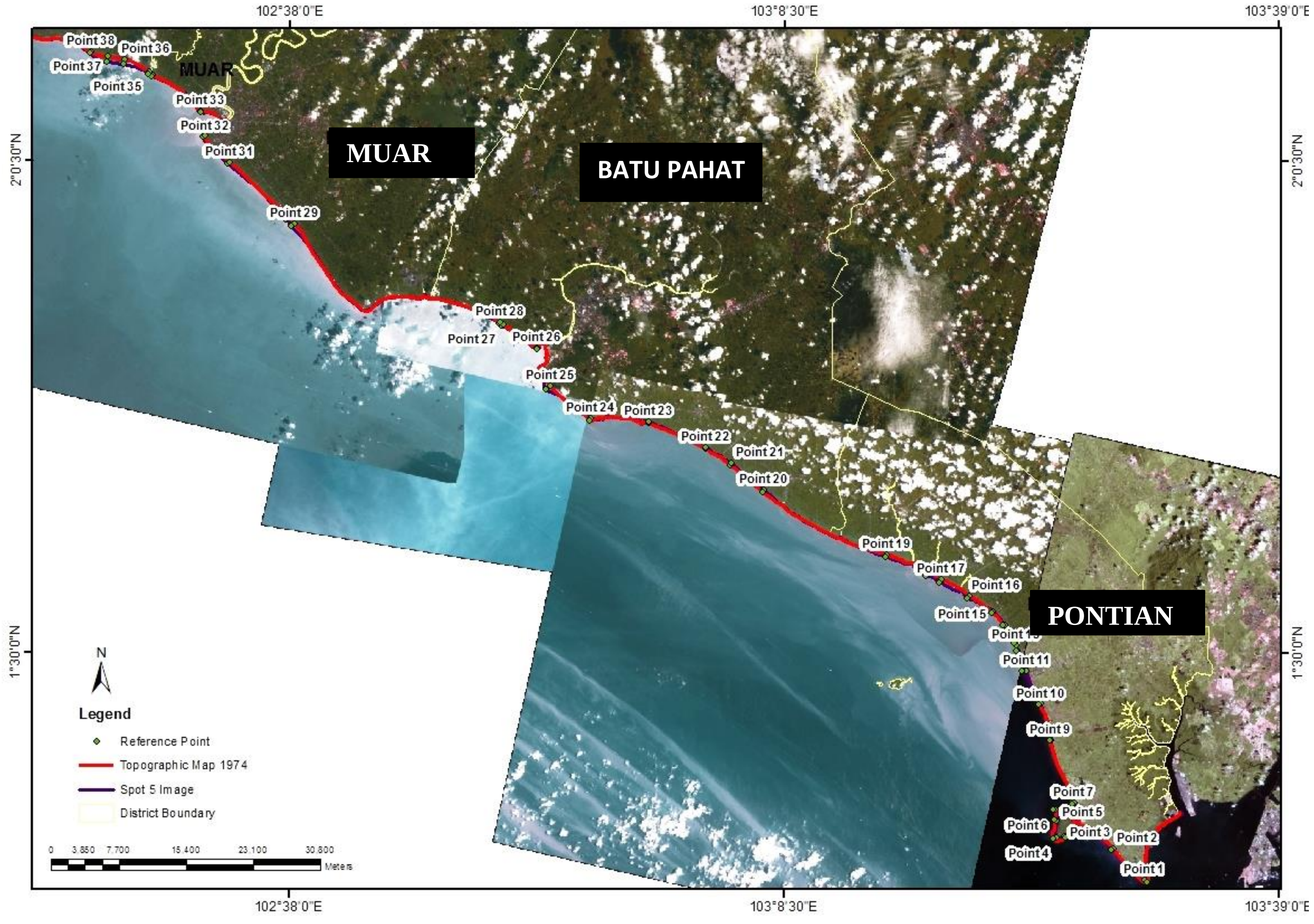

Figure 1.2 Shoreline change analysis from Muar to Pontian (DID, 2012b)

Coastal hazard management requires the understanding of shoreline dynamics and should also consider on potential future hazard such as the increased of sea level due to future global warming. Thus, the state government of Johor should take serious measures to avoid any destruction by relocating infrastructures to landward from the shoreline and replant mangroves along the coast. Mapping coastal area in a large scale makes it possible to identify the potentially highly vulnerable areas (McLaughin and Cooper, 2010).

In this study, the analysis was mainly in Minyak Beku, Batu Pahat, Johor, Malaysia. Minyak Beku is once categorized under category erosion based on National Coastal Erosion Study (NCES), 1985. Category 3 is acceptable erosion; areas where the rates of erosion are such that no significant danger to economic, agricultural, transportation, recreational and demographic values and with structures intended to protect such values, is likely within foreseeable futures such as 10 to 15 years. However, the effect of coastal erosion at Minyak Beku is significant nowadays due to development, agricultural and dredging activities. The study area for LiDAR covered about 810 hectare as shown in red polygon (Figure 1.3), while the study area for bathymetry covered about 5km from the shoreline. The integration of bathymetry and LiDAR data perhaps can provide CVI information for coastal management.

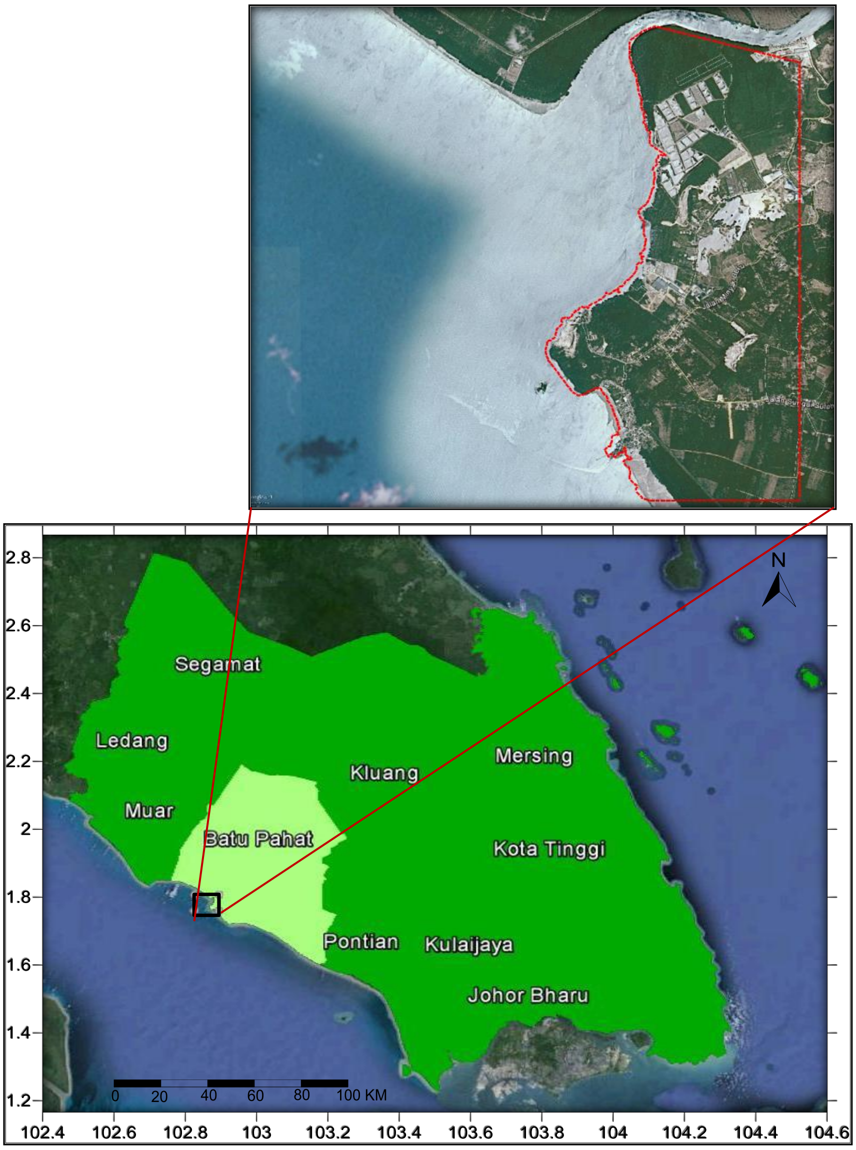

Figure 1.3 Location of Minyak Beku (Google Earth)

1.4.3 Data Used in the Research

During this research shoreline data from 1988, 2009, and 2014 were used. Shoreline data 1988 were delineated from topographic maps while shoreline data 2009 and 2014 were delineated based on Mean High Water (MHW) values during that year, based on the availability of the data. Shoreline change rate information were determined from the shoreline data available, while coastal slope information were extracted from the coastal mapping. Only two elements of CVI were extracted. Shoreline changes rate was processed using Digital Shoreline Analysis System Software, while the percentage of coastal slope was determined using Google Earth Software.

1.5 Significance of Study

Previous study shows that shoreline analysis is done with the result from 2D images such as from aerial photography and satellite images that is based on topographic map (DID, 2012b). The analyses of shoreline were based on the shoreline changes positions without knowing the geomorphology of that area. What is lacking in Malaysia is the inability to develop a large scale coastal mapping for CVI analysis (DID 2012a). The significance of this study is to develop a seamless coastal mapping from bathymetry and LiDAR data to provide detailed information of coastal area. Coastal information such as shoreline change rate and steepness of coastal slope is a subset of CVI that can be generated from the coastal mapping. It gives coastal information for coastal planning and management. For an example, the historical shoreline position shall then be compared with the current position in an attempt to make future predictions as consequences of the climate change and human intervention factors.

Seamless coastal mapping is a basis for an analysis of shoreline changes position, steepness of coastal slopes, and for coastal management decision. A continuous area of land and water gives a complete picture of coastal zones. However, there are some limitations in order to generate a continuous mapping from land to water area such as different types of datum, difficulties to perform surveys on hazardous and shallow water area, cost and time constraint. Hence, the LiDAR data and bathymetry data were integrated to develop a seamless coastal mapping. The results of this study will benefits the developer and government to propose a suitable measure to overcome a new problem in coastal area.

1.6 Thesis Outline

This thesis is divided into five chapters. This description of each chapter is as follows:

Chapter 1: Introduction

Chapter one is an introductory chapter in this study. It contains the basis of researches which are; research background on CVI, problem statement, research objectives, research approach, scope of study and significance of the study.

Chapter 2: Literature Review

This chapter reviews the literature based on previous research and literatures related with this study. Generally, the reading materials are covering the basic concept of CVI and a basic element in mapping such as horizontal and vertical projection and implementation of CVI in Malaysia. This section is intended to provide a basic knowledge of CVI information's.

Chapter 3: Research Methodology

This chapter describes clearly the methods used for integrating bathymetry data and LiDAR data. Chapter three answers the research question from Table 1.1. A seamless coastal mapping was developed as a medium for CVI analysis. Shoreline change rate and coastal slope (%) information were extracted from the coastal mapping.

Chapter 4: Result and Analysis

In this chapter, the elements of CVI which are shoreline change rate and coastal slope were extracted from the coastal mapping. The quality of the coastal mapping were analyze based on visual assessment and statistical methods. These data were ranked according to CVI rankings. The detailed discussion were carried out to identify the factors of coastal erosion and to identify the vulnerable area.

Chapter 5: Conclusion and Recommendation

This chapter summarizes the result of the study based on analysis. A few recommendations were proposed for further research and to improve the study in the future.

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