COASTAL INUNDATION RISK ASSESSMENT USING MULTI-MISSION SATELLITE ALTIMETER AND DIGITAL ELEVATION MODELS

NUR FADILA BINTI KHALID

UNIVERSITI TEKNOLOGI MALAYSIA

COASTAL INUNDATION RISK ASSESSMENT USING MULTI-MISSION SATELLITE ALTIMETER AND DIGITAL ELEVATION MODELS

NUR FADILA BINTI KHALID

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy

Faculty of Built Environment and Surveying
Universiti Teknologi Malaysia

JULY 2018

DEDICATION

To My Sweet and Loving Parents

Khalid Mat Hashim and Rashidah Allies

And

To My Dearest Brothers and Sisters

Ridzuan, Firdaus, Izzati and Nadiatul

This Humble Work Is A Sign of My Love To You!

ACKNOWLEDGEMENT

Alhamdullilah – Praise be to ALLAH S.W.T., the Most Compassionate and the Most Merciful, Whose blessings and mercy have helped me throughout my life. There is no will and no strength unless with His help

I would like to express my sincere gratitude to those who have made this thesis possible. My most sincere thanks go to my supervisors, Dr. Ami Hassan Bin Md Din, Assoc. Prof Kamaludin Bin Hj. Mohd Omar and Dr. Mohd Faisal Bin Abdul Khanan for their expert guidance, encouragement, advices, and patience, and for supporting and assisting me in every possible way. Thank you for teaching me that every mistakes is just learning experience.

I am also indebted to the Malaysian Ministry of Higher Education for sponsoring my master degree study. I also acknowledge the help of the Department of survey and Mapping Malaysia (DSMM), Department of Irrigation and Drainage (DID), Delft University of Technology (TU Delft) for their assistance in supplying the data. Many thanks to U.S Geological Survey, ICGEM, CGIAR-CSI, NASA, NIMA, METI, and German Aerospace Center (DLR) for making this work possible by freely providing DEMs and EGM96 data.

My sincere appreciations also extend to all my friends who are always support me through the ups and downs together especially Astina, Farah, Suraya, Amalina, Najihah, Nini, Nabila, Khalilah, Adilla, Kak Anim, Kak Nazirah, Kak Anom, Afiq, Amirul, Adzlan, Amir, Yusof, Abazu and Abang Faiz Pa’suya. Thanks for always listening to me, supporting me, encouraging me and helping me in any conditions. It is a very wonderful experience to get know all of you and I am very grateful for that.

As for the utmost appreciation and gratitude, I would like to thanks the King and Queen of my heart, Khalid Bin Mat Hashim and Rashidah binti Allies, for their unconditional love, supports, prayers, blessings, sacrifices and never giving up on me. Your awesome parenting has shaped me into who I am today. To my dearest brothers and sisters, thanks you for believing in me and showers me with your love and fantastic supports. Let us be a good daughters and sons that our parents will be proud of.

Finally, thanks you very much again for everyone that have contributed directly and indirectly in completing this thesis. Without their continued support, advices, and critics, this thesis would not have been the same as presented here.

ABSTRACT

One of the most significant impacts of climate change is sea-level rise. The rate of global sea levels is expected to continue rising in the future, which would cause severe damage to coastal areas and threaten the nearby population. This study aims to determine the inundation of coastal areas caused by the effects of rising sea levels using a combination of satellite altimeters, Global Positioning Systems, and Digital Elevation Models. The inundation scenarios for the return periods of 5, 25, 45, 65, and 85 years were successfully simulated using the hydrological model obtained from altimetry data. The inundation scenarios were overlain on land elevation datasets to estimate the inundation risks. Vulnerability assessments of inundation risk maps were analysed in ArcGIS environment to develop maps for vulnerable areas and populations. The study revealed that by the year 2100, sea level is projected to be rising at the rate of between 32cm to 50cm for the sub-chosen sea over the Malaysian seas. The results from the assessment also show that Kelantan area is highly vulnerable to the sea-level rise event. At the local scales, nearly 1km^2 of total land area is projected to be inundated under the smallest scenario. Under the higher sea level scenarios, over 8.2 km^2 is potentially inundated with up to 46,000 people around the coastal and flood plain area of Kelantan, especially near Kota Bahru, could be affected. This study has successfully shown the integration of hydrological model to produce the inundation risk maps, taking into account the extent of land area covered under sea level at different scenarios. Findings are valuable to help the local authorities in developing strategic coastal management plans to address challenges of the climate change.

ABSTRAK

Salah satu dari kesan yang paling penting dari perubahan iklim adalah peningkatan paras laut. Kadar paras laut global dijangka terus meningkat pada masa akan datang, yang akan menyebabkan kerosakan teruk di kawasan pesisir pantai dan mengancam penduduk berhampiran. Kajian ini bertujuan untuk menentukan pembanjiran kawasan pesisiran yang disebabkan oleh kesan kenaikan paras laut dengan menggunakan gabungan altimeter satelit, sistem penentududukan sejagat, dan model ketinggian digital. Senario pembajiran bagi tempoh pulangan 5, 25, 45, 65 dan 85 tahun telah berjaya disimulasikan menggunakan model hidrologi yang diperoleh dari data altimeter. Senario pembanjiran ini telah dilapisi dengan data ketinggian tanah bagi menggangarkan risiko berlakunya limpahan banjir. Penilaian kerentanan peta risiko pembanjiran dianalisis dalam persekitaran ArcGIS bagi membangunkan peta kawasan dan populasi yang akan terancam. Kajian ini menjelaskan bahawa pada tahun 2100, paras laut dijangka meningkat pada kadar di antara 32cm sehingga 50cm bagi sub-kawasan laut yang terpilih di perairan Malaysia. Hasil daripada penilaian ini menunjukkan bahawa kawasan Kelantan sangat terdedah kepada kejadian kenaikan paras laut. Pada skala tempatan, hampir 1km^2 daripada jumlah kawasan tanah dijangka akan dilimpahi di bawah senario terkecil. Di bawah senario paras laut tertinggi, lebih dari 8.2km^2 berpotensi dilimpahi dengan hampir 46,000 orang di sekitar kawasan persisiran pantai dan dataran banjir di Kelantan terutamanya di kawasan Kota Bahru boleh terjejas. Kajian ini berjaya memperlihatkan penyepaduan model hidrologi bagi menghasilkan peta risiko pembanjiran dengan mengambilkira perluasan kawasan tanah yang dilitupi dibawah paras laut pada senario yang berbeza. Oleh demikian, dapatan ini dapat memberi manfaat bagi membantu pihak berkuasa tempatan dalam membangunkan pelan pengurusan pantai strategik untuk menangani cabaran perubahan iklim.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

3B	-	Backwards-Viewing
3D	-	Three-Dimensional
3N	-	Near Infrared Spectral Band
AOCGM	-	Atmospheric-Oceanic General Circulation Model
AR4	-	Fourth Assessment Report
ASI	-	Agenzia Spaziale Italiana
ASTER-GDEM	-	Advanced Spaceborne Thermal Emission And Reflection Radiometer-Global Digital Elevation Model
ATSR	-	Along Track Scanning Radar
CDED	-	Canadian Digital Elevation Data
CDF		Cumulative Distribution Function
CH_4	-	Methane
CNES	-	Centre National D'etudes Spatiales
CO_2	-	Carbon Dioxide
DBMS	-	Database Management System
DEM	-	Digital Elevation Model
DID	-	Department Of Irrigation And Drainage
DLR	-	Deutsches Zentrum Für Luft- Und Raumfahrt
DORIS	-	Doppler Orbitography And Radiopositioning Integrated By Satellite
DOSM	-	Department Of Statistics Malaysia
DSM	-	Digital Surface Model
DSMM	-	Department Of Surveying And Mapping Malaysia
DTED	-	Digital Terrain Elevation Data
DTM	-	Digital Terrain Model

EGM96	-	Earth Geopotential Model 1996
ER	-	Entity-Relationship
ERS-1	-	European Remote-Sensing Satellite-1
ESA	-	European Space Agency
GDEx	-	Global Data Explorer
GDM2000	-	Geodetic Datum Of Malaysia 2000
GDTS	-	Geodetic Datum Transformation Suite
GEOS-3	-	Geodynamics And Earth Ocean Satellite 3
Geosat	-	Us Geodetic Satellite
GFO	-	Geosat Follow-On
GIS	-	Geographic Information System
GMTED2010	-	Global Multi-Resolution Terrain Elevation Data 2010
GPS	-	Global Positioning System
GtCO_2 eq/yr		Gigatonnes CO_2-equivalents per year
GTOPO30	-	Global 30 Arc- Second Elevation
H_2O	-	Water Vapour
HRTE-3	-	High-Resolution Terrain Elevation- Level 3
ICGEM	-	International Centre For Global Earth Model
IMU	-	Inertial Measurement Unit
IPCC	-	Intergovernmental Panel On Climate Change
IRLS	-	Iteratively Re-Weighted Least Squares
ISS		Instantaneous Sea Surface
LiDAR	-	Light Detection And Ranging
LECZ		Low Elevation Coastal Zone
MAD	-	Median Absolute Deviation
METI	-	Japan’s Ministry Of Economy, Trade, And Industry
MRSO	-	Malayan Rectified Skew Orthomorphic
MSS	-	Mean Sea Surface
MyCIIS	-	Malaysia Inundating Information System
MyGeoid	-	Malaysia Geoid Model
MyRTKnet	-	Malaysia Real-Time Kinematic GNSS Network
N_2O	-	Nitrous Oxide
NAHRIM	-	National Hydraulic Research Institute Of Malaysia

NASA	-	National Aeronautics And Space Administration
NE	-	Northeast
NED	-	National Elevation Dataset
NGA	-	National Geospatial-Intelligence Agency
NIMA	-	National Imagery And Mapping Agency
R	-	Radar Range
RADS	-	Radar Altimeter Database System
RCP	-	Representative Concentration Pathway
RMSE	-	Root Mean Square Error
RTK	-	Real-Time Kinematic
SALT	-	Satellite Altimeter
SAR	-	Synthetic Aperture Radar
SLA	-	Sea Level Anomalies
SPOT 5	-	Satellite Pour Observation De La Terre
SLR		Satellite Laser Ranging
SRES	-	Special Report Emission Scenarios
SRTM	-	Shuttle Radar Topography Mission
SSH	-	Sea Surface Height
SST	-	Sea Surface Temperature
STD	-	Standard Deviation
TanDEM-X	-	Terrasar Add-On for Digital Elevation Measurements
USFNR	-	Upper South Fork Of The New River
USGS	-	United States Geological Survey
USO	-	Ultra-Stable Oscillator
WGS84	-	World Geodetic System 1984

LIST OF SYMBOLS

β	-	Monthly Average Changes Of Sea Level From One Period To Another
ΔR_{dry}	-	Dry Tropospheric Correction.
ΔR_{iono}	-	Ionospheric Correction.
ΔR_{ssb}	-	Sea State Bias Correction.
ΔR_{wet}	-	Wet Tropospheric Correction
A_t (x,y)	-	Vulnerable Area At The Period Time
b	-	Gradient Value
C	-	Speed Of The Radar
C	-	Connectivity Of Water And Surface
c	-	Y-Intercept (Estimated Value Of Y When T =0)
Cs	-	Constants Value Of Each Grid Cell Size
D (h)	-	Damage Caused By The Inundation Depth (H) Which Is Associated With A Certain Return Flood Period
E	-	Elevation (DEM) Value At Location X, Y
f(h)	-	Possibility Density Functions Of The Flooded Level (H)
FC_t (x,y)	-	Inundated Area At The Location (X,Y)
H	-	Height Of The Mass Of The Spacecraft Above The Ellipsoid Reference
H	-	Orthometric Height
h	-	Ellipsoidal Height
h_0	-	Lower Integration Water Limit In Threshold Which Flood Damage Occurs.
h_{atm}	-	Dynamic Atmospheric Correction

h_D	-	Dynamic Sea Surface Height
H_{diff}	-	Elevation Error
h_{geoid}	-	Geoid Correction
h_{GPS}	-	GPS Geometric Height
h_i	-	Vector Of Leverages That Used To Adjust The Residuals
H_{model}	-	Elevation Of The Explored Point In DEM
$H_{reference}$	-	Elevation of The GPS Points.
H_{SALT}	-	Altitude of Altimeter
h_{tides}	-	Tides correction
i	-	Integer Specifying The "Bathtub", Adjoining, Cardinal, or Diagonal and Cardinal Points of Connectivity Rules.
In lev	-	Future Projections of Sea Level
K	-	Tuning Constant Commonly Approximated as 4.685
N	-	Geoid height (egm96)
n	-	Number of Samples Data
N_{Geoid}	-	Height of The Geoid
P^o	-	Population Value at That Year (For Example in The Year 2010, Population Value is 250,000)
P^t	-	Population value after the t years
r	-	An average of annual population growth rate (in %)
r_i	-	Least-squares residuals
R_{SALT}	-	Range from the satellite
S	-	Robust variance given by median absolute deviation (mad) of the residuals 0.6745
t	-	Number of the years that need to be projected
t	-	Number of the years (for example 10 years)
$w(s_0)$	-	Distance matrix
w_{oi}	-	The Distance Between Location s_o and s_i
X and Y	-	Independent and Dependent Variable
x_i and y_i	-	Single samples indexed with i
$\hat{Y}$	-	Projected value of the y variable for the selected value of t
$\hat{Z}(s_0)$	-	The prediction value of variable z at point i
$Z(s_i)$	-	Sample value in point i

α	-	An exponent determining the weight (a value of 2 is often used) of each observation
ε	-	Standard error of measurement
λi	-	Dependent quantity weight for the measured value at the i
r	-	Pearson correlation coefficient

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Consistently changing global sea levels is one of the main pressing issues closely related to anthropogenic effects. Global warming factors prominently effect sea level rise include increased in ocean heat content as well as melting ice sheets and glaciers. Rising sea levels tends to make headlines during extreme events such as storm surges generated by a tropical or extra-tropical cyclone. Furthermore, an increment of sea level can also cause severe damage to coastal landscapes when inundates low-lying land.

According to Church et al. (2010), global sea levels rose by an average 1.7 mm per year during the 20th century based on data from coastal and island tide-gauges. Near-global measurements of sea level since 1993 to 2006 by satellite altimeters show an average global sea level rise of 3.1 ± 0.4 mm per year. In the Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change (IPCC), it is clearly stated that sea level trends are projected to increase by between 18 cm to 59 cm from 1980-2000 to 2090-2100 (IPCC, 2007). Coastal areas are affected in various ways due to climate change since the coast is sensitive to higher sea levels that will eventually inundate low-lying land (wetland and dry) as well as suffering from storm surges and shoreline erosion.

As the world's ocean rise, coastal and lowland areas will permanently disappear. Even a small increase in sea level magnitude, it can have devastating effects on coastal regions, especially in areas with high population densities and other living species such as flora and fauna. Strauss and Kulp (2014) mentioned in their new analysis on climate change that, up to 216 million people currently live in vulnerable areas that will be affected by rising sea levels and could be regularly or permanently inundated within the next 100 years. Thus, it is not surprising if rising sea levels and their potential impact has attracted global attention in the last two decades.

Coastal inundation or flooding is defined as a natural hazard caused by rising sea levels that affects human populations and built-up areas around coastlines. In order to determine the vulnerability of coastal lands to incremental increases in sea level and inundation from flooding events, high resolution land elevation is an important parameter. Especially, inundation extent and depth-averaged in low-lying deltaic were observed to be extremely touchy to terrain representation.

In this study, sea level effects were investigate by combining related land and water information. This information can be retrieved from the combination of multi-sensor technology such satellite altimeter, Digital Elevation Models (DEM) and Global Positioning System (GPS). Sea level trends over Malaysian seas due to global climate change within 23 years can be retrieved from a combination of multi-mission satellite altimeters. Meanwhile, Shuttle Radar Topography Mission (SRTM), Advanced Spaceborne Thermal Emission and Reflection Radiometer-Global Digital Elevation Model (ASTER-GDEM), Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010), TerraSAR add-on for Digital Elevation Measurements (TanDEM-X), airborne Light Detection and Ranging (LiDAR), and Global Positioning System (GPS) were used to produce a high accuracy Digital Elevation Model (DEM) over land areas. Thus, these techniques allow us to monitor the rate of sea level and to simulate the future impact of sea level in the Malaysian coast area.

1.2 Problem Statement

The coastal areas and island of Malaysia are valuable assets in term of supporting local activities such as infrastructure, recreation, agriculture, forestry, fishing, aquaculture, and tourism. More importantly, these activities are threatened by rising sea levels due to the future negative impacts on coastal environment which threatens societies, ecosystem, and infrastructure. Inundation or coastal flooding events occur where the water level exceeds land elevation. This event can happen from numerous physical processes, including extreme rainfall, storm surges, tsunamis, high tidal ranges and increased sea levels. However, this study only focused on the impact of rising sea levels and does not take into account on other events that can affect coastal areas. Due to the aforementioned facts, a better understanding of the possible sea level change scenarios in this region is imperative since Malaysia is surrounded by water. With rising sea level becoming a pressing issues in the coastal areas, a comprehensive assessment should be conducted to assess the vulnerability of Malaysia coastal region to projected inundations.

For certain periods, the sea level changes can be derived from coastal tide gauges observations for a specific area. In the meantime, the average sea level around the world is not rising uniformly at all locations, thus causing difficulties in predicting sea level changes with traditional tide gauge instruments due to the uneven topographical distribution of tide gauge stations mounted at shore area and no long period continuous deep ocean data (Din, 2014). Tide gauges only measured relative sea level, which reflects the vertical land motion effect, but to study the sea levels, absolute sea level is necessary (Feng et al., 2013). Poor maintenance and low quality data has resulted difficulties in monitoring long-term sea levels using tide gauge stations (Hannah, 2010). With the latest satellite technology development such as satellite altimeters, absolute sea level can be estimated, particularly along the coastline of Malaysian.

Nowadays, satellite altimeters are widely used to improve ocean dynamic studies and to determine absolute sea level from space in order to overcome the problems of existing techniques. In contrast with the tide gauge method, satellite altimeters can provide long-term sea level data and monitor sea level changes over Malaysian seas, especially in the deep sea. By measuring absolute sea level from the altimetry data, projecting the future rate sea level can be done for the next 100 years. To obtain the best results for absolute sea level for the Malaysian region, all geographical effects such as geoid undulation, sea state bias, tidal range variation, and atmospheric effects that response to sea surfaces must be modelled and removed from sea surface height.

One of the most prominent issues caused by rising sea levels is coastal inundation over low-lying areas. Floods from the sea can overflow lowland areas such as beach ridges, coastal plains, deltas, lagoons, and bays, and this would threaten communities around the Malaysian coastal region. Elevation data play a major role in determining the extent to which inundating areas will be affected by sea level increments. More importantly, the spatial resolution and vertical accuracy of the Digital Elevation Model (DEM) data sources has a great influence in determining accuracy when mapping of the entire coastal areas that potentially impacted by coastal inundation when it’s done later.

Topographical surfaces with high-resolution data derived from LiDAR are extensively used in inundation modelling. However, LiDAR data is not available for some area in Malaysia region. Common publicly available DEM datasets are frequently used in coastal inundation risk assessments as an alternative method to overcome this problem. DEMs like ASTER GDEM with 1 arc-seconds horizontal resolution data set, SRTM with 1 and 3 arc-seconds horizontal resolution data set, and GMTED2010 with 7.5 arc-seconds horizontal resolution data set can be assessed and freely downloaded without charge, and are ready to use for modeling, even though their accuracy and resolutions are relatively low (Sande et al., 2012; and Eakins et al., 2014).

Therefore, various analyses were performed to study the spatial variation of the sea level rise over Malaysian seas using 23 years data of satellite altimeter data and external quality validation of DEMs vertical accuracy data to understand the proper modelling of coastal vulnerability assessments. Reliable vulnerability assessment information is important to government agencies, local communities, environmental scientists, and the private sector for providing some solutions through proper management and adaptive planning to mitigate the impacts of rising sea levels on coastal areas in the future.

1.3 Research Question

The questions of this study are main arguments that need to be answered in order to design the objectives of this study. They are:

a) How does the resolution and accuracy of DEM affect inundation risk assessment?

b) What are the trends for sea level change for each Malaysian Sea and what is the magnitude of future rising sea levels for the next 100 years?

c) Which areas are likely to be inundated due to sea level events with different magnitude values?

1.4 Research Aims and Objectives

The aim of this study is to determine the potential coastal inundation areas due to sea level changes using multi-mission satellite altimeters and DEM dataset. In order to achieve the research aim, the specific objectives are as follows:

i. To evaluate the accuracy of DEM model from open sources data and LIDAR data.

   Different types of DEM data are available to the public in different spatial resolutions. The relationship and correlation between ground *control point data retrieved from GPS levelling and DEM datasets was analyzed in order to provide better DEM estimation for coastal areas.*

ii. To estimate spatial sea level trends and projection along the Malaysian coastal zone.

Sea level trends were quantified using robust fit regression analysis and simple linear regression. After that, the magnitude of sea level rise was projected for the next 100 years.

iii. To perform a coastal vulnerability assessment based on an inundation risk map.

Vulnerability assessment in this study concentrates on risk assessment of the area affected areas and human populations around coastal areas as a result of coastal inundation due to rising sea levels.

1.5 Research Scope

The research scope of this study are as follows:

i. The development of sea level rise simulations and the assessment of coastal vulnerabilities over the Malaysian region. The Strait of Malacca, the South China Sea, the Sulu Sea, and the Celebes Sea were selected due to their relationship to the Malaysian coastal region in terms of their geophysical and geological conditions (see Figure 1.1).
   a) Coastal zone around Kelantan (covering a small area using the highly accurate DEM data).
   b) Malaysian coastal zone (covering regional areas using the low accurate DEM data).

Figure 1.1: Malaysia Map (Worldatlas, 2017).

ii. A ground truth dataset from Global Positioning System (GPS) were used to evaluate the vertical accuracy of Digital Elevation Model (DEM) data from SRTM, ASTER, GMTED2010, and TanDEM-X. Airborne Light Detection and Ranging (LiDAR) data over the Kelantan area was used in this study for data validation purposes.

iii. Altimetry datasets retrieved from RADS (Radar Altimeter Database System) from eight multi-mission satellite altimeters (TOPEX/POSEIDON, ERS-1, ERS-2, Jason-1, Jason-2, Saral, Cryosat2 and EnviSat) from 1993-2015 were used to obtain sea level anomalies over Malaysian Seas. The increase in sea level rates and its magnitude was calculated using simple linear and robust fit regression. Scenarios of rising sea levels were projected for 2020, 2040, 2060, 2080 and 2100.

iv. In the simulation process, sea level values and suitable elevation models from global DEMs and LiDAR data played the important role in identifying the inundated areas. Potential inundation maps were displayed using Geographic Information System (GIS) software.

v. For estimating vulnerable areas due to the rising sea levels, there is a variety of commercial, open source, and scientific software. In this study, Global

Mapper 18 and GIS tool (ArcGIS version 10.3), which has the capability to handle multiprocessing and various map models were used to model vulnerable areas and estimate inundation damage caused by coastal inundation with additional information such as human population data. The detail of this analysis is explained in Chapter 4

1.6 Significance of the Study

The findings from this study are expected to provide some benefits and impacts as follows:

i. This study proves whether or not elevation datasets from LiDAR and global DEMs is suitable for use in natural hazard identification such as coastal inundation.

ii. In terms of providing long term sea level data for coastal vulnerability assessments due to coastal inundation, the use of multi-mission satellite altimeters derive absolute sea level anomalies and to understand sea level trends over Malaysia Seas is more reliable than tide gauge data due to its sparse data distribution and high maintenance cost. The results of this analysis are expected to be valuable for other studies related to coastal environmental issues such as coastal inundation, coastal erosion, and impacts on the marine ecosystem.

iii. Accurate, updated, and frequent rising sea level data projections are important because it can determine sea level increments in the future. The results of rising sea level projections for Malaysian Seas will become an important reference to helping authorities in coastal planning and development in the future.

iv. This study highlights the potential areas along the Malaysian coastline that could be inundated due to rising sea levels based on projected sea level values and DEM data sources. The generation of inundation risk maps could increase public awareness about coastal inundation, especially those who live in low-lying areas and near coastlines.

v. The results of this study will serve as a pre-indicator to designing long-term inundation mitigation to reduce vulnerability by assessing potential risks impacts that may occur in the future.

vi. The development of the simulation model, will help local government agencies such as the Department of Irrigation and Drainage (DID) and National Hydraulic Research Institute of Malaysia (NAHRIM) to predict the increments of sea level and flood discharge for the next events. However, in order to complete inundation forecasting operations in the future, this model needs to be integrated with other parameters such as hydraulic models, tidal models, wind speed models, wave heights, etc.

1.7 General Methodology

Figure 1.2 illustrates the data flow as well the main processing steps taken for this study. This study is comprised of four major phases as shown in Figure 1.3:

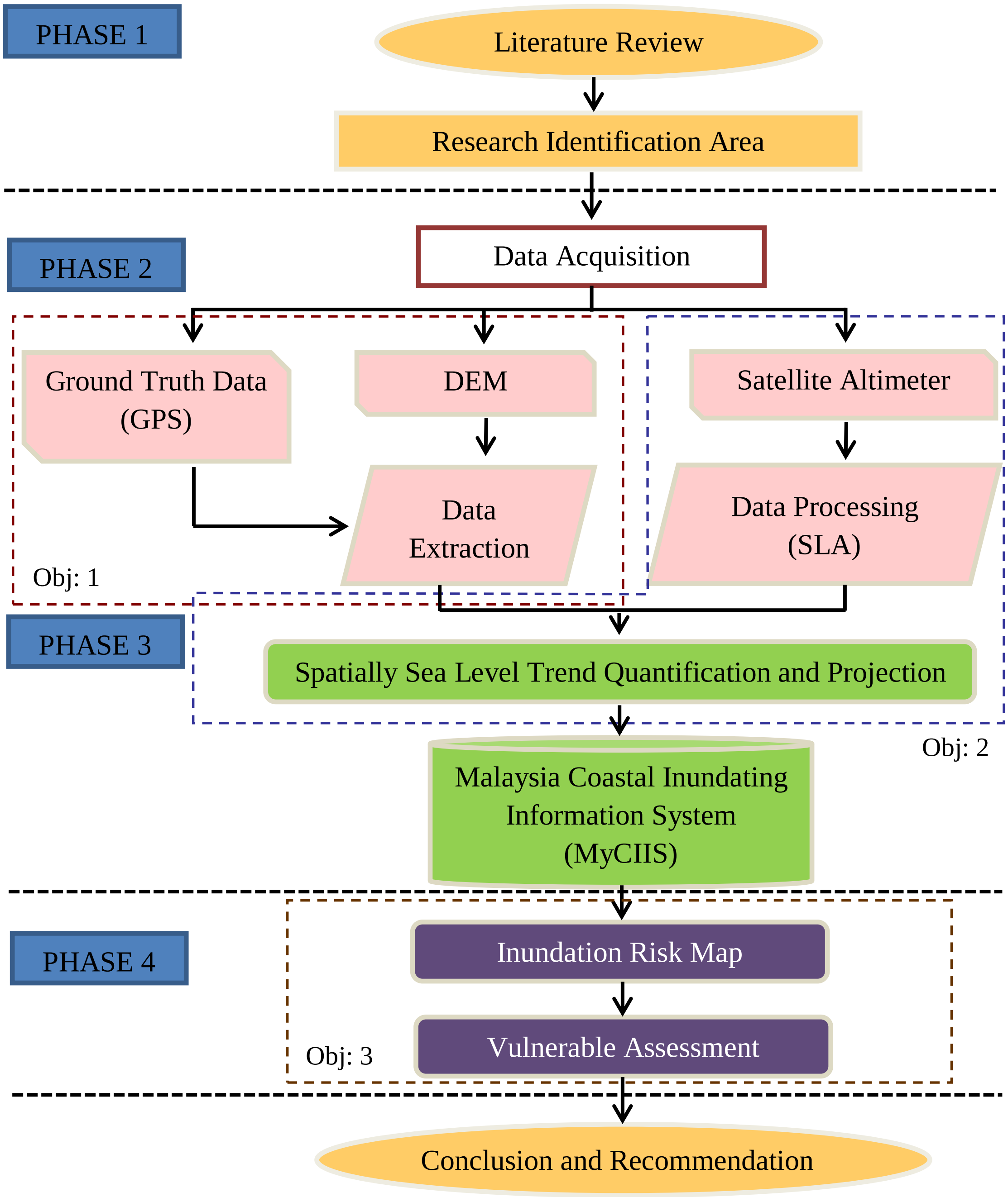

Figure 1.2: Framework of the Research Study.

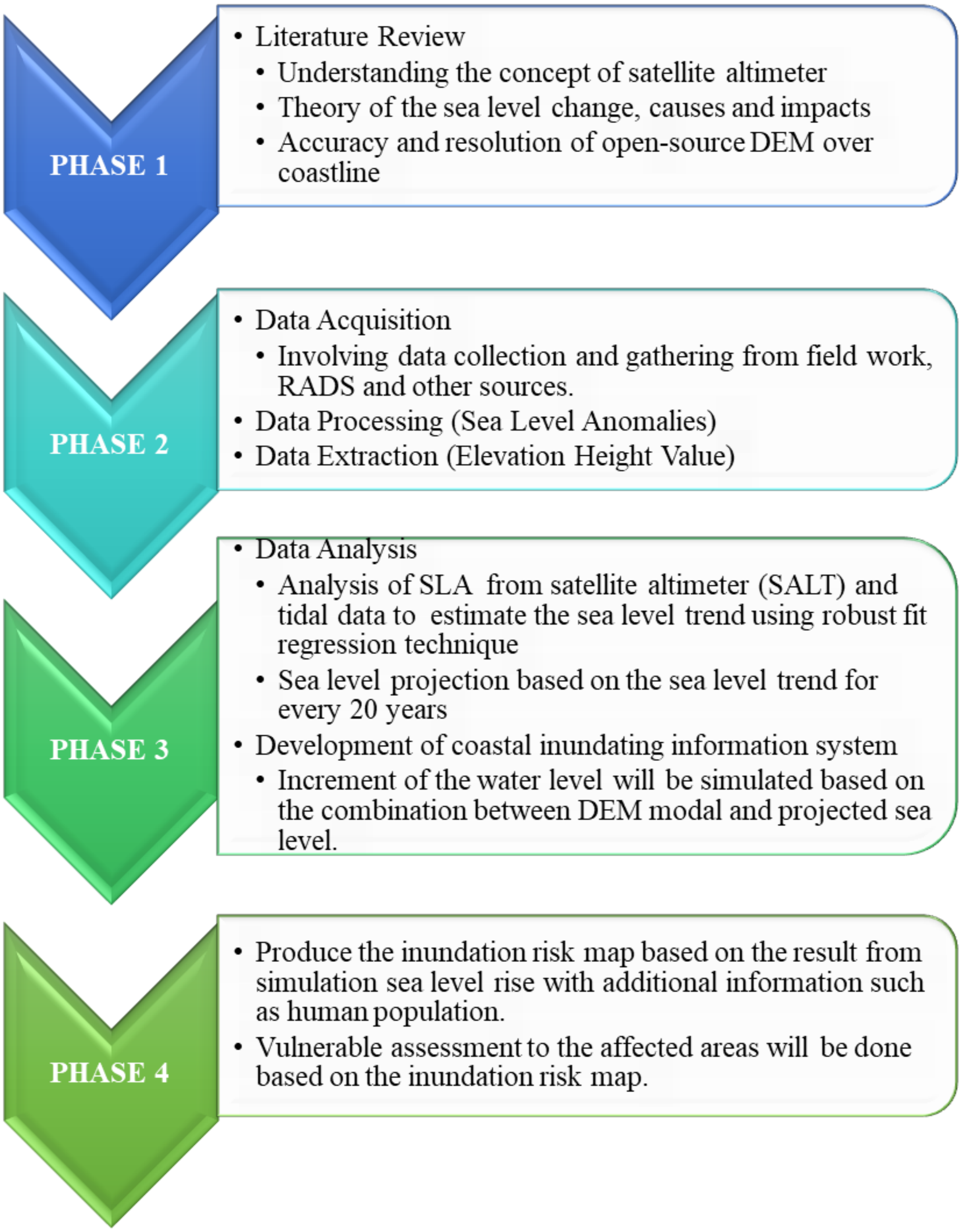

Figure 1.3: Research Structure Organization.

1.8 Thesis Structure

This thesis has been structured into five (5) chapters. The description of each chapter is outlined as follows:

Chapter 1 introduces this study, which provides a brief review of climate change and global warming issues, sea level rise, topographic data and vulnerabilities in coastal region. The problem statement, research aim, research scope, and study significance were identified by constructing clear research objectives.

Chapter 2 reviews the literature based on previous and related research. An overview of the sea level rise scenarios and the impact of climate change over on coastal areas is reviewed in this chapter. Moreover, knowledge of theoretical and principle of altimeter satellites is important to deriving sea level data from multi-mission satellite altimeters to determine sea level anomalies. Besides that, this study also attempts to elaborate the topographic effect and resolution of elevation data used to predict coastal inundation and related damages along coastal regions. Understanding the methodology used for estimating coastal inundation and vulnerabilities is essential to designing the sea level simulation framework.

Chapter 3 clearly describes the methods used in this study to obtain its results. An assessment of DEM datasets in terms of vertical accuracy with validation from ground truth data from GPS measurements are discussed in this chapter. Furthermore, the overall process of sea level derivation using Radar Altimeter Database System (RADS), sea level trend analysis using robust fit and linear regression, and projected rising sea levels over 100-year for the Malaysian Seas extensively described. At the end, coastal inundation modelling was performed to estimate flood risk uncertainty over coastal areas by combining sea level projection and elevation data are demonstrated in this chapter.

Chapter 4 discusses the relationship and correlation between ground control points retrieved from GPS levelling and DEM dataset to provide better DEM estimation within coastal areas specifically for coastal inundation risk assessment. In addition, the derivation of absolute sea level anomalies and changes in sea level magnitudes every 20 years until 2100 are described in details. A detailed discussion was carried out to identify an uncertainty impacts sea level changes for the particular areas based on coastal inundation modelling.

Chapter 5 summarize the findings of this study based on the analysis, its contribution, and implications. Several recommendation and suggestions are proposed in order to improve future studies.

References

Abrams, M., & Hook, S. (2002). ASTER User Handbook Version 2. Jet Propulsion (Vol. 2003). Retrieved from Abrams2002NASA.pdf

Al-Buloshi A, A.-H. S. and, & Y, C. (2014). GIS-based Framework for the Simulation of the Impacts of Sea Level Rise and Coastal Flooding on Oman. Journal of Earth Science & Climatic Change, 05(10). http://doi.org/10.4172/2157-7617.1000238

Alias, N. E., Mohamad, H., Chin, W. Y., & Yusop, Z. (2016). Rainfall analysis of the Kelantan big yellow flood 2014. Jurnal Teknologi, 78(9-4), 83–90. http://doi.org/10.11113/jt.v78.9701

Anderson, O. B., & Scharroo, R. (2011). Range and Geophysical Corrections in Coastal Regions: And Implications for Mean Sea Surface Determination. In S. Vignudelli, A. G. Kostianoy, P. Cipollini, & J. Benveniste (Eds.), Coastal Altimetry (pp. 103–145). Springer Heidelberg Dordrecht London New York. http://doi.org/10.1007/978-3-642-12796-0

Anthony, D., Shaaban, A. J., Aung, T. H., Saleh, E., Hamid, R. A., & Osman, A. (2015). Sea Level Changes Along the Coast of Sandakan Town , Sabah , Malaysia : Projection and Inundation Coverage.

Athmania, D., & Achour, H. (2014). External validation of the ASTER GDEM2, GMTED2010 and CGIAR-CSI- SRTM v4.1 free access digital elevation models (DEMs) in Tunisia and Algeria. Remote Sensing, 6(5), 4600–4620. http://doi.org/10.339 AVISO. (2017, May 9).

AVISO Satellite Altimetry Data. Retrieved from http://www.aviso.altimetry.fr/en/missions.html0/rs6054600

Avtar, R., Yunus, A. P., Kraines, S., & Yamamuro, M. (2015). Evaluation of DEM generation based on Interferometric SAR using TanDEM-X data in Tokyo. Physics and Chemistry of the Earth, 83-84, 166–177. http://doi.org/10.1016/j.pce.2015.07.007

Bureau of Meteorology and CSIRO. (2014). The State of the Climate. Australia. Retrieved from www. csiro.au/State-of-the-Climate-2014

Cazenave, A., & Cozannet, G. Le. (2013). Sea level rise and Its Coastal Impacts. Earth's Future, 2, 15–34. http://doi.org/10.1002/2013EF000188.Received

CGIAR-CSI. (2017, August 1). SRTM 90m Digital Elevation Database v4.1. Retrieved from CGIAR - Consortium for Spatial Information (CGIAR-CSI): http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1

Chelton, D. B., Ries, J. C., Haines, B. J., Fu, L. L., & Callahan, P. S. (2001). Satellite Altimetry. In L. L. Fu & A. Cazenave (Eds.), Satellite Altimetry and Earth Sciences (5th ed., pp. 1–135). Academic Press.

Church, J. A., Clark, P. U., Cazenave, A., Gregory, J. M., Jevrejeva, S., Levermann, A., … Unnikrishnan, A. S. (2013). Sea level change. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, … P. M. Midgley (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1137–1216). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://doi.org/10.1017/CB09781107415315.026

Church, J. A., Nichols, R., Hay, J. E., & Gornitz, V. (2010). Ice and Sea-level Change. GLOBAL OUTLOOK FOR ICE AND SNOW (Vol. Chapter 6C).

Danielson, J., & Gesch, D. (2011). Global Multi-resolution Terrain Elevation Data 2010. Terrain (Vol. 2010).

Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D., & Yan, J. (2007). The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis. Policy Research Working Paper, 1–51. Retrieved from http://econ.worldbank.org/external/default/main?ImgPagePK=64202988&entityID=000016406_20070209161430&pagePK=64165259&theSitePK=469382&piPK=585673

Davis, D., Sutherland, M., & Jaggan, S. (2010). Augmenting Tide Gauge Data with Satellite Altimetry in the Observation of Sea Level Rise in the Caribbean

Augmenting Tide Gauge Data with Satellite Altimetry in the Observation of Sea Level Rise in the Caribbean. FIG Congress 2010, XXIV(Facing the Challenges – Building the Capacity), 1–12.

Din, A. H. M. (2014). Sea Level Rise Estimation and Interpretation in Malaysian Region Using Multi-Sensor Techniques, Ph.D.(September).

Din, A. H. M., Omar, K. M., Naeije, M., & Ses, S. (2012). Long-term sea level change in the Malaysian seas from multi-mission altimetry data. International Journal of Physical Sciences, 7(10), 1694–1712. http://doi.org/10.5897/IJPS11.1596

Din, A. H. M., Reba, M. N. M., Omar, K. M., Pa'suya, M. F., & Ses, S. (2015). Sea Level Rise Quantification Using Multi-Mission Satellite. Asian Association on Remote Sensing, (Atmosphere & Oceanography & Climate change).

Din, A. H. M., Ses, S., Omar, K. M., Naeije, M., Yaakob, O., & Pa'suya, M. F. (2014). Derivation of Sea Level Anomaly Based on the Best Range and Geophysical Corrections for Malaysian Seas using Radar Altimeter Database System (RADS). Jurnal Teknologi, 4, 83–91.

Din, A. H. (2014). Sea Level Rise Estimations And Interpretation In Malaysian Region Using Multi-Sensor Technique. Doctor Philosophy. Universiti Teknologi Malaysia, Skudai.

DOSM, Department Of Statistics Malaysia. (2011). Taburan Penduduk dan Ciri-ciri Asas Demografi.

DSMM. (2016, June 18). Geoidal Map. Retrieved from Department of Survey and Mapping Malaysia (DSMM): https://www.jupem.gov.my/v1/en/product-services/geoidal-map

Du, X. P., Guo, H. D., Fan, X. T., Zhu, J. J., Yan, Z. Z., & Zhan, Q. (2012). Vertical Accuracy Assessment of SRTM and ASTER GDEM Over Coastal Regions of China: A Comparative Analysis. Asian Association on Remote Sensing, 33(4), 887–897. http://doi.org/10.3799/dqkx.2013.087

Eakins, B. W., & Grothe, P. R. (2014). Challenges in Building Coastal Digital

Elevation Models. Journal of Coastal Research, 297(2007), 942–953. http://doi.org/10.2112/JCOASTRES-D-13-00192.1

Ezer, T., & Atkinson, L. P. (2014). Accelerated flooding along the U.S. East Coast: On the impact of sea-level rise, tides, storms, the Gulf Stream, and the North Atlantic Oscillations. Earth's Future, 2(8), 362–382. http://doi.org/10.1002/2014EF000252

Feng, G., Jin, S., & Zhang, T. (2013). Coastal sea level changes in Europe from GPS, tide gauge, satellite altimetry and GRACE, 1993-2011. Advances in Space Research, 51(6), 1019–1028. http://doi.org/10.1016/j.asr.2012.09.011

Fraile-Jurado, P., & Ojeda-Zújar, J. (2013). The importance of the vertical accuracy of digital elevation models in gauging inundation by sea level rise along the Valdelagrana beach and marshes (Bay of Cádiz, SW Spain). Geo-Marine Letters, 33(2-3), 225–230. http://doi.org/10.1007/s00367-012-0317-8

Fu, L. L. (2010). Determining Ocean Circulation and Sea Level from Satellite Altimetry: Progress and Challenges. In V. Barale, J. F. R. Gower, & L. Alberotanza (Eds.), Oceanography from Space: Revisited (pp. 1–375). http://doi.org/10.1007/978-90-481-8681-5

Fu, L. L., & Cazenave, A. (2001). Satellite altimetry and Earth sciences. (L. L. Fu & A. Cazenave, Eds.).

Fu, L. L., Chelton, D. B., & Zlotnicki, V. (1988). Satellite altimetry - Observing ocean variability from space. Oceanography, 1(2), 4–11. http://doi.org/10.5670/oceanog.1988.01

Fuchs, R. J. (2010). Cities at risk: Asia's coastal cities in an age of climate change. Asia Pacific Issues, (96), 1–12.

Gorokhovich, Y., & Voustianiouk, A. (2006). Accuracy assessment of the processed SRTM-based elevation data by CGIAR using field data from USA and Thailand and its relation to the terrain characteristics. Remote Sensing of Environment, 104(4), 409–415. http://doi.org/10.1016/j.rse.2006.05.012

Gottwald, M., Fritz, T., Breit, H., Schättler, B., & Harris, A. (2016). The Global

TanDEM-X Digital Elevation Model and the Terrestrial Impact Crater Record.

Gunduz, O., & Kara, G. T. (2015). Influence of DEM Resolution on GIS-Based Inundation Analysis, (JUNE).

Hannah, J. (2010). The Difficulties in Using Tide Gauges to Monitor Long-Term Sea Level Change. International Federation of Surveyors, XXIV(FACING THE CHALLENGE – BUILDING THE CAPACITY), 1–10.

Hansen, J. E. (2007). Scientific reticence and sea level rise. Environmental Research Letters, (March), 1–9. http://doi.org/10.1088/1748-9326/2/2/024002

Hirt, C., Filmer, M. S., & Featherstone, W. E. (2010). Comparison and validation of the recent freely available ASTER-GDEM ver1, SRTM ver4.1 and GEODATA DEM-9S ver3 digital elevation models over Australia. Australian Journal of Earth Sciences, 57(3), 337–347. http://doi.org/10.1080/08120091003677553

Holland , P. W., & Welsch, R. E. (1977). Robust regression using iteratively reweighted least-squares. Communications in Statistics - Theory and Methods : Volume 6, Issue 9, 813-827.

ICGEM. (2016, February 18). Calculation of Gravity Field Functionals on Ellipsoidal Grids. Retrieved from International Centre for Global Earth Models : http://icgem.gfz-potsdam.de/calc

IPCC. (2001). Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. (J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, … C. A. Johnson, Eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (S. Solomon, D. Qin, M. Manning, M. Marquis, K. Averyt, M. M. B. Tignor, & H. L. M. Jr., Eds.) (Vol. 53). United Kingdom and New York, NY, USA: Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,. http://doi.org/10.1017/CBO9781107415324.004

IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (R. K. Pachauri & L. A. Meyer, Eds.).

Ismail, W. R., & Haghroosta, T. (2018). Extreme weather and floods in Kelantan state , Malaysia in December 2014, 3(1), 231–244.

Jackson, S. L. (2008). Correlational Methods and Statistics. In Research Methods and Statistics : A Critical Thinking Approach (pp. 140–163). http://doi.org/10.1007/s13398-014-0173-7.2

Jeofry, M. H., & Rozainah, M. Z. (2013). General observations about rising sea levels in Peninsular Malaysia. Malaysian Journal of Science, 32(SPEC. ISS.), 363–370.

Jung, B., & Moreira, A. (2017, July 8). New 3D world map – TanDEM-X global elevation model completed. Retrieved from DLR German Aerospace Center: http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10081/151_read-19509/#/gallery/24516

Karlsson, J. M., & Arnberg, W. (2011). Quality analysis of SRTM and HYDRO1K: a case study of flood inundation in Mozambique. International Journal of Remote Sensing, 32(1), 267–285. http://doi.org/10.1080/01431160903464112

Krieger, G., Moreira, A., Fiedler, H., Hajnsek, I., Werner, M., Younis, M., & Zink, M. (2007). TanDEM-X : A Satellite Formation for, 45(11), 3317–3341.

Leon, J. X., Heuvelink, G. B. M., & Phinn, S. R. (2014). Incorporating DEM uncertainty in coastal inundation mapping. PLoS ONE, 9(9), 1–12. http://doi.org/10.1371/journal.pone.0108727

Lohani, B. (2017, August 3). Airborne altimetric LiDAR for topographic data collection: Issues and applications. Retrieved from GEOSPATIAL WORLD: https://www.geospatialworld.net/article/airborne-altimetric-lidar-for-topographic-data-collection-issues-and-applications/

Luana, S., Hou, X., & Wang, Y. (2015). Assessing the Accuracy of SRTM Dem and Aster Gdem Datasets for the Coastal Zone of Shandong Province, Eastern

China. Polish Maritime Research, 22(s1), 15–20. http://doi.org/10.1515/pomr-2015-0026

Marfai, M. A., & King, L. (2008). Potential vulnerability implications of coastal inundation due to sea level rise for the coastal zone of Semarang city, Indonesia. Environmental Geology, 54(6), 1235–1245. http://doi.org/10.1007/s00254-007-0906-4

McGranahan, G., Balk, D. L., & Anderson, B. (2007). The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environment and Urbanization, 19(1), 17–37. http://doi.org/10.1177/0956247807076960

Meng, Q., Liu, Z., & Borders, B. E. (2013). Assessment of regression kriging for spatial interpolation – comparisons of seven GIS interpolation methods. Cartography and Geographic Information Science, 40(1), 28–39. http://doi.org/10.1080/15230406.2013.762138

Merz, B., Elmer, F., & Thieken, A. H. (2009). Significance of " high probability / low damage " versus " low probability / high damage " flood events. Earth, 1033–1046.

Milbert, D. G. (1991). COMPUTING GPS-DERIVED ORTHOMETRIC HEIGHTS WITH THE GEOID90 GEOID HEIGHT MODEL. Technical Papers of the 1991 ACSM-ASPRS Fall Convention. American Congress on Surveying and Mapping, Washington, D.C, A46–55.

Moreno, E. L., Bazoglu, N., Mboup, G., & Warah, R. (2008). State of the World's Cities 2008/2009 HARMONIOUS CITIES. (R. Warah, Ed.). United Nations Human Settlements Programme (UN-HABITAT).

Mukherjee, S., Joshi, P. K., Mukherjee, S., Ghosh, A., Garg, R. D., & Mukhopadhyay, A. (2012). Evaluation of vertical accuracy of open source Digital Elevation Model (DEM). International Journal of Applied Earth Observation and Geoinformation, 21(1), 205–217. http://doi.org/10.1016/j.jag.2012.09.004

Murdukhayeva, A., August, P., Bradley, M., LaBash, C., & Shaw, N. (2013).

Assessment of Inundation Risk from Sea Level Rise and Storm Surge in Northeastern Coastal National Parks. Journal of Coastal Research, 291, 1–16. http://doi.org/10.2112/JCOASTRES-D-12-00196.1

Naba, N. I., Razak, A. A. A., Tajudin, S., & Shukri, A. S. (2015). Submission of Raster DTM,DSM, and River Structures Products. Supply Of Raster Dtm & Dsm Derived From Archived Kelantan Lidar Data.

NAHRIM. (2010). The Study of Impacts of Climate Change on Sea Level Rise in Malaysia. National Hydraulic Research Institute of Malaysia.

NASA. (2016, January 26). Shuttle Radar Topography Mission (SRTM). Retrieved from National Aeronautics and Space Administration: http://www2.jpl.nasa.gov/srtm/

ONI. (2017, October 13). Oceanic Niño Index. Retrieved from El Niño and La Niña Years and Intensities: http://ggweather.com/enso/oni.htm

Overpeck, J. T., & Weiss, J. L. (2009). Projections of future sea level becoming more dire. Proceedings of the National Academy of Sciences of the United States of America, 106(51), 21461–21462. http://doi.org/10.1073/pnas.0912878107

PO.DAAC. (2017, May 9). Physical Oceanography Distributed Active Archive Center. Retrieved from NASA EOSDIS PO.DAAC: https://podaac.jpl.nasa.gov/Altimetric_Data_Information

Poulter, B., & Halpin, P. N. (2008). Raster modelling of coastal flooding from sea-level rise. International Journal of Geographical Information Science, 22(2), 167–182. http://doi.org/10.1080/13658810701371858

Radzi, A. B. A., & Ismail, P. H. B. (2013). Trend Analysis of Sea Level Rise for West Coast of Peninsular Malaysia (Lumut). International Conference on Emerging Trends in Engineering and Technology (ICETET'2013) Dec. 7-8, 2013 Patong Beach, Phuket (Thailand) Trend, 3, 113–115.

Rahmstorf, S. (2007). Projecting Future Sea-Level Rise. Retrieved from http://science.sciencemag.org/content/315/5810/368

Reyes, S. R. C., & Blanco, A. C. (2012). Assessment of coastal vulnerability to sea level rise of Bolinao, Pangasinan using remote sensing and geographic information systems. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 39(B6), 167–172.

Rizzoli, P., Bräutigam, B., Kraus, T., Martone, M., & Krieger, G. (2014). Relative height error analysis of TanDEM-X elevation data. ISPRS Journal of Photogrammetry and Remote Sensing, 73(2012), 30–38. http://doi.org/10.1016/j.isprsjprs.2012.06.004

Rizzoli, P. (2017, August 1). Satellite SAR Systems. Retrieved from Microwaves and Radar Institute, German Aerospace Center DLR: http://www.dlr.de/hr/en/desktopdefault.aspx/tabid-2328/3447_read-46107

Sande, B. van de, Lansen, J., & Hoyng, C. (2012). Sensitivity of Coastal Flood Risk Assessments to Digital Elevation Models. Water, 4(3), 568–579. http://doi.org/10.3390/w4030568

Sanders, B. F. (2007). Evaluation of on-line DEMs for flood inundation modeling. Advances in Water Resources, 30(8), 1831–1843. http://doi.org/10.1016/j.advwatres.2007.02.005

Scorzini, A. R., & Leopardi, M. (2017). River basin planning: from qualitative to quantitative flood risk assessment: the case of Abruzzo Region (central Italy). Natural Hazards. http://doi.org/10.1007/s11069-017-2857-8

Shortridge, A., & Messina, J. (2011). Spatial structure and landscape associations of SRTM error. Remote Sensing of Environment, 115(6), 1576–1587. http://doi.org/10.1016/j.rse.2011.02.017

Simav, Ö., Şeker, D. Z., & Gazioğlu, C. (2013). Coastal inundation due to sea level rise and extreme sea state and its potential impacts: Cukurova Delta case. Turkish Journal of Earth Sciences, 22(4), 671–680. http://doi.org/10.3906/yer-1205-3

Smith, K., & Ward , R. (1998). Flood: Physical Processes and Human Impacts. Wiley,Chichester.

Strauss, B., & Kulp, S. (2014). New Analysis Shows Global Exposure to Sea Level

Rise | Climate Central, 2–3. Retrieved from http://www.climatecentral.org/news/new-analysis-global-exposure-to-sea-level-rise-flooding-18066

Tachikawa, T., Manabu Kaku, Iwasaki, A., Gesch, D., Oimoen, M., Zhang, Z., … Carabajal, C. (2011). ASTER Global Digital Elevation Model Version 2 – Summary of Validation Results. Japan Space Systems. Retrieved from http://www.jspacesystems.or.jp/ersdac/GDEM/ver2Validation/Summary_GDEM2_validation_report_final.pdf

Tam, T. H. (2014). Flood Risk Mapping Using Geospatial Technologies and Hydrodynamic Modelling In Kota Tinggi, Johor. Universiti Teknologi Malaysia.

Tam, T. H., Ibrahim, A. L., Abd Rahman, M. Z., & Zulkifli, M. (2013). Flood Risk Mapping using Geospatial Technologies and Hydraulic Model. 34th Asian Conference on Remote Sensing 2013, ACRS 2013.

Teng, J., Vaze, J., Dutta, D., & Marvanek, S. (2015). Rapid Inundation Modelling in Large Floodplains Using LiDAR DEM. Water Resources Management, 29(8), 2619–2636. http://doi.org/10.1007/s11269-015-0960-8

Tsubaki, R., & Fujita, I. (2010). Unstructured grid generation using LiDAR data for urban flood inundation modelling. Hydrological Processes, 24(11), 1404–1420. http://doi.org/10.1002/hyp.7608

Turner, A. B., Colby, J. D., Csontos, R. M., & Batten, M. (2013). Flood modeling using a synthesis of multi-platform LiDAR data. Water (Switzerland), 5(4), 1533–1560. http://doi.org/10.3390/w5041533

Union of Concerned Scientists (UCS). (2013). Causes of Sea Level Rise: What the Science Tells Us, Fact Sheet, 1–8. Retrieved from http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/Causes-of-Sea-Level-Rise.pdf

USDA. (2017, MAY 22). Global Reservoirs/Lakes (G-REALM). Retrieved from United State Department of Agriculture, Foreign Agricultural Service: http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/

USGS. (2017, August 1). U.S. Geological Survey,Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010). Retrieved from USGS Science for Changing World: https://lta.cr.usgs.gov/GMTED2010

Vignudelli, S., Kostianoy, A. G., Cipollini, P., & Benveniste, J. (2011). Coastal Altimetry. (S. Vignudelli, A. G. Kostianoy, P. Cipollini, & J. Benveniste, Eds.)Springer-Verlag Berlin Heidelberg 2. http://doi.org/10.1017/CBO9781107415324.004

Wessel, B. (2013). TanDEM-X Ground Segment DEM Products Specification Document, 39. Retrieved from https://tandemx-science.dlr.de/

Worldatlas. (2017, April 7). World Map / Asia / Malaysia. Retrieved from Worldatlas.com: http://www.worldatlas.com/webimage/countrys/asia/my.htm

Yunus, A. P., Avtar, R., Kraines, S., Yamamuro, M., Lindberg, F., & Grimmond, C. S. B. (2016). Uncertainties in Tidally Adjusted Estimates of Sea Level Rise Flooding (Bathtub Model) for the Greater London. Remote Sensing, 8(5). http://doi.org/10.3390/rs8050366

Zhang, K. (2011). Analysis of non-linear inundation from sea-level rise using LIDAR data: A case study for South Florida. Climatic Change, 106(4), 537–565. http://doi.org/10.1007/s10584-010-9987-2

Zhao, S., Cheng, W., Zhou, C., Chen, X., Zhang, S., Zhou, Z., … Cha, H. (2011). Accuracy assessment of the ASTER GDEM and SRTM3 DEM: an example in the Loess Plateau and North China Plain of China. International Journal of Remote Sensing, 32(23), 8081–8093. http://doi.org/10.1080/01431161.2010.532176

Ziary, Y., & Safari, H. (2007). To Compare Two Interpolation Methods : IDW , KRIGING for Providing Properties (Area) Surface Interpolation Map Land Price . District 5 , Municipality of Tehran area 1 . Integration The Vlsi Journal, (May), 13–17.