MANGROVE MIGRATION DUE TO SEA LEVEL RISE

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To my beloved husband,

Thank you for your love, patience and understanding

To my beloved Ayah and Emak,

Thank you for bringing me into this world

To my friends and families,

Thank you for being a part of this journey

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ABSTRACT

The coastal zone of Pulau Kukup is characterized by muddy substrates and is classified as a micro-tidal coast. Potential impacts of sea level rise were studied to relate the effects of tidal inundation regime associated with accelerated SLR and mangrove migration for the next centuries. The primary objective of this research is to simulate and estimate the potential mangroves migration under several conditions of sea level rise scenarios projected for the years 2025, 2050 and 2100. Another goal of this study is to evaluate the Coastal Vulnerability Index (CVI) and develop the supplementary maps for the island. Vegetation map were developed from WorldView-2 data within SPRING 5.2 software. The Digital Terrain Model from IFSAR data, were processed in ArcGIS 9.3 to produce the mangrove migration map. The CVI study showed that the northern and southern sectors are highly vulnerable risk to sea level rise and this accounted for 42% from Pulau Kukup shorelines. From the field survey analyses and mangrove vegetation map, *Rhizophora apiculata* and *Rhizophora mucronata* dominates an outer part of the mangrove belts, accounting for 89% from the total sampled trees. The study concluded that, mangrove plant will tolerate to the inundation change in order of *Sonneratia alba, Rhizophora mucronata, Rhizophora apiculata, Bruguiera parviflora, Brugueira cylindrica* and *Xylocarpus moluccensis.* A series of mangrove migration map for 2025, 2050 and 2100 sea level rise scenarios shows an adjustment to tidal inundation class due to increase of seawater level. Mangroves from the lower zones (Z2 and Z3) migrate into the higher zone (Z4) as a response to sea level rise. In the worst case scenario, more than 25% of the mangrove forest will be converted to the open water due to a 1.3 metre sea level rise. The total land loss in the year 2100 was estimated at 69.75 hectare (Case study 1), 73.52 hectare (Case study 2) and 148.92 hectare (Case study 3). The worst case scenarios will possibly lead to the extinction of *Xylocarpus moluccensis* at Pulau Kukup when zone Z4 was begin to disappear from the year 2050 SLR projection. In conclusion, the findings showed that the mangrove migrations will occur if the tidal inundation were modified by future sea water level. It is a strategic response developed by mangrove species to maintain the preferable condition for their optimal growth and species colonisation. This research approach can be applied to other mangrove forest at regional scale to identify the potential mangrove response in a simple way for basic information of future development and planning for scientist, engineer, researchers and decision makers.

ABSTRAK

Zon pesisir pantai Pulau Kukup mempunyai ciri-ciri substrat berlumpur dan diklasifikasikan sebagai pesisir pantai mikro-pasang surut. Potensi impak Kenaikan Aras Laut telah dikaji untuk mengaitkan kesan inundasi pasang surut yang berkaitan dengan kepantasan kenaikan aras laut dan migrasi pokok bakau untuk abad seterusnya. Objektif utama kajian ini adalah meramal dan menganggar migrasi berpotensi bakau dalam pelbagai senario kenaikan aras laut yang diunjurkan bagi tahun 2025, 2050 dan 2100. Matlamat lain kajian ini adalah menilai 'Coastal Vulnerability Index (CVI)' dan menghasilkan peta-peta sokongan pulau tersebut. Peta tumbuhan telah di bangunkan menggunakan data WorldView-2 melalui perisian SPRING 5.2. Peta migrasi bakau seterusnya di hasilkan menggunakan Model Paramuka Berdigit dari data IFSAR, melalui aplikasi ArcGIS 9.3. Hasil kajian 'CVI', menunjukkan sektor-sektor yang terletak di kawasan utara dan selatan mengalami risiko keterancaman yang tinggi akibat kenaikan aras laut dan ini mewakili 42% dari jumlah keseluruhan pesisir pantai Pulau Kukup. Analisis dari tinjauan tapak dan peta tumbuhan bakau mendapati *Rhizophora apiculata* dan *Rhizophora mucronata* mendominasi bahagian luar lilitan bakau sebanyak 89% dari jumlah keseluruhan sampel pokok-pokok. Kajian ini menyimpulkan bahawa tahap toleransi pokok bakau terhadap perubahan inundasi adalah seperti berikut iaitu *Sonneratia alba, Rhizophora mucronata, Rhizophora apiculata, Bruguiera parviflora, Brugueira cylindrica* dan *Xylocarpus moluccensis.* Satu siri peta migrasi bakau bagi senario kenaikan aras laut di hasilkan untuk tahun 2025, 2050 dan 2100 menunjukkan pelarasan kepada kelas inundasi pasang surut di sebabkan oleh kenaikan aras air laut. Bakau daripada zon yang lebih rendah (Z2 & Z3) akan mengalami migrasi ke zon yang lebih tinggi (Z4) akibat kenaikan aras air laut. Senario terburuk menunjukkan lebih dari 25% hutan bakau akan hilang akibat kenaikan 1.3 meter aras air laut. Jumlah penyusutan kawasan bakau pada tahun 2100 dianggarkan sebanyak 69.75 hektar (Kajian kes 1), 73.52 hektar (Kajian kes 2) dan 148.92 hektar (Kajian kes 3). Senario kes terburuk mungkin akan membawa kepada kepupusan *Xylocarpus moluccensis* di Pulau Kukup apabila zon Z4 mula mengalami penyusutan melalui unjuran peningkatan aras air laut pada tahun 2050. Kesimpulanya, hasil kajian menunjukkan migrasi bakau dijangka berlaku apabila terdapat perubahan inundasi pasang surut disebabkan kenaikan aras laut di masa hadapan. Ia merupakan satu tindakbalas strategik spesis bakau bagi mengekalkan keadaan yang sesuai untuk pertumbuhan yang optimum dan pengkolonian spesis. Pendekatan yang di bangunkan melalui kajian ini boleh diguna pakai di kawasan hutan bakau lain pada skala serantau untuk mengenalpasti potensi tindakbalas bakau dengan cara yang mudah untuk maklumat asas pembangunan dan perancangan masa hadapan oleh ahli-ahli saintis, jurutera, penyelidik dan pembuat keputusan.

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LIST OF ABBREVIATIONS

CD	-	Chart Datum
CVI	-	Coastal Vulnerability Index
DBH	-	Diameter at Breast Height
DEM	-	Digital Elevation Model
DID	-	Department of Irrigation and Drainage
DSAS	-	Digital Shoreline Analysis System
DSM	-	Digital Surface Model
DSMM	-	Department of Survey and Mapping Malaysia
DTM	-	Digital Terrain Model
EGM	-	Earth Gravitational Model
ENVI	-	Environment for Visualizing Image
EPR	-	End Point Rate
EVI	-	Environmental Vulnerability Index
GIS	-	Geographic Information System
IFSAR	-	Interferometric Synthetic Aperture Radar
IPCC	-	Intergovernmental Panel on Climate Change
LIDAR	-	Light Detection and Ranging
LMSL	-	Local Mean Sea Level
MRSA	-	Malaysian Remote Sensing Agency
MSMD	-	Malaysia Survey and Mapping Department
NAHRIM	-	National Hydraulic Research Institute Malaysia
NCVI	-	National Coastal Vulnerability Index
NHC	-	National Hydrographic Center
NIMA	-	National Imagery and Mapping Agency
ORI	-	Ortho-Rectified Image
PAN	-	Panchromatic Image
PCQM	-	Point-Centre-Quarter Method

PVI	-	Physical Vulnerability Index
SAR	-	Synthetic Aperture Radar
SCR	-	Shoreline Changes Rate
SLR	-	Sea Level Rise
TIN	-	Triangulated Irregular Network
USGS	-	United State of Geological Survey

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Natural threats originating from the ocean waters have become a major concern to coastal communities. Sea-Level-Rise (SLR) phenomenon was identified by IPCC, (2001) as an expected problem faced by intertidal communities resulting from global climate change. Projection of global sea level rise by several models indicated an increase from 12-22cm in seawater surface during the 20th century (Thomas et al., 2004). Solomon et al., (2007) projected an increase of 0.19-0.59 m in 21st century based on data projection of 1999-2099. The long term effects of SLR will reduce the quality of intertidal ecosystems due to habitat deterioration (Gilman et al., 2007). SLR may combine with other coastal hazard (e.g: tsunami) and maximize the impacts to the coastal ecosystem.

Some major physical impacts of SLR have been listed by Titus, (1991) such as increase in inundation, coastal erosion, exacerbated coastal flooding and increase in the salinity intrusion to estuaries and aquifers. Marfai and King, (2008) conducted a research on the impacts of SLR to the Semarang coast in Indonesia and found that the tidal inundation and land subsidence were increased by the impact of SLR.

Inundation is the most obvious physical impact of sea level rise (Cooper et al., 2008). The conversion of dryland to wetland or the wetland to open sea is anticipated, resulting from the changes of normal inundation processes due to SLR. The inundation risk to coastal communities had been extensively studied by many authors from all over the world, such as Marfai and King, (2008a) in Indonesia, Kuhn and Tuladhar, (2011) at Australia, Tian et al., (2010) in China, and later Di Nitto et al., (2014) in Kenya. As the sea level rises, the inundation level and distances, period of submergence and frequencies will change accordingly. These modifications will affect the intertidal ecosystem, especially the low-lying wetland ecosystem such as the mangroves. Mangrove chains will face mass fatality, while the survivability rate of mangrove trees would be reduced.

Mangroves grow widely all over the world between Indo-Pacific Region, South and Central America to Africa. Majority of mangrove populations are distributed between equatorial line to latitudes 30 degree north and south. According to Tomlinson, (1986) mangrove species variability will decrease with increasing latitudes, therefore more than 40 species of mangrove are found in the Eastern group (Australia, South East Asia, Western Pacific, India and East Africa), compared to 8 species found in the Western Group (South America, Florida, Atlantic South America, Pacific North, Western Africa and Caribbean). Mangroves comprise less than 2% of the total land area in Malaysia. There are 641,886 ha of mangrove forests in Malaysia, of which 57% is found in Sabah and 26% in Sarawak while remaining 17% in Peninsular Malaysia (Kamaruzzaman, 2013).

In recent years, mangroves are declining at an alarming rate. A global reduction of approximately 25% has been observed since 1980, and the mangrove area today is less than 15million ha (Valiela et al., 2001). Kathiresan and Rajendran, (2005) conducted a study after the December 2004 tsunami event, and listed certain places in India, Bangladesh, Malaysia, Thailand and Indonesia as not severely impacted by the lethal power of the tsunami waves, because a chain of coastal mangrove vegetation helped to dissipate the wave energy and lowered the impacts to the coastal areas.

Despite the capability in coastal defense mechanism, mangrove is a long-living and slow growing plant (Woodroffe, 1990). Mangroves cannot keep pace to sea level rise when the intensity of changes is drastic. Mangroves will respond to the impacts of SLR as their adaptation strategies. Gilman et al., (2008) described that the mangrove response in term of the mangrove position to sea level rise can be classified under four categories (Figure 1.1). They are ‘stable (no migration), ‘seaward migration, ‘landward migration' and 'landward migration' (obstructed).

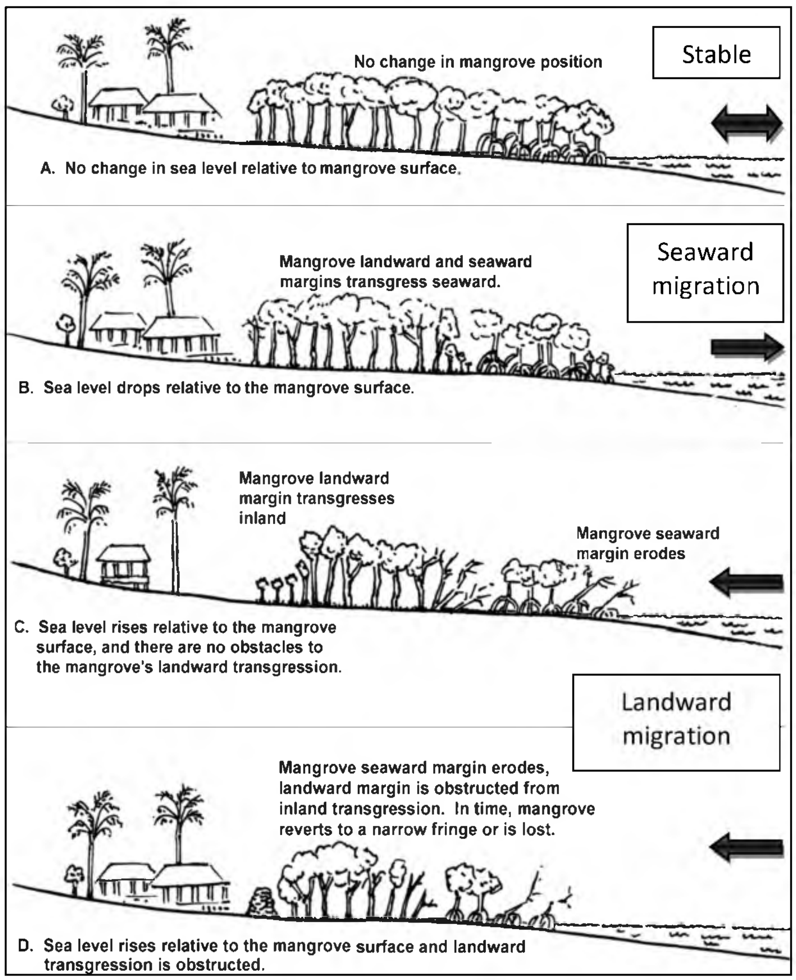

Figure 1.1 Mangrove response to relative sea level rise (Gilman et al., 2008)

Landward migration is a natural response of mangrove species to the anticipated effects of SLR. Mangroves will migrate via seedling recruitment and vegetative reproduction to new habitat and form a new zonation pattern (Gilman et al., 2008). This response is crucial for mangrove species to maintain the preferable zones for their growth and expansion. Basic information and predictions of local mangrove response to the long term effect of SLR are therefore significant. In the end, the prediction of mangrove migration will provide useful information for site planning and conservation strategies to offset the anticipated losses.

1.2 Problem Statement

The loss of mangrove can be disastrous as evidenced by past events. The Tsunami event on 26th December 2004 triggered by a magnitude 9.15 earthquake in the Indian Oceans released a series of devastating tsunami waves and caused enormous environmental damage to northwestern Peninsular Malaysia (Kamaruzzaman, 2013). The post-tsunami assessment in affected areas showed that healthy mangroves communities not only broke the impacts of the waves, but also trapped debris and prevented people from being washed out to sea, which was a major cause of death in other countries. In normal situation, when waves are small, mangroves also contribute to dissipating the wave energy and reduce the coastal erosion. It is reported that the height of wind and swell waves is reduced by 13-66 percent within the first 100m of mangroves belt (Dahdouh-Guebas and Koedam, 2006). To perform these functions effectively, the mangrove green belt should be wide enough and contain high diversity of species and age groups.

In Malaysia, mangroves comprise less than 2% of the total land area. 40% of mangrove area had been reduced since 1980 due to shrimp pond farming, woodchip industry and natural phenomenon (Sujahangir et al., 2014). Sea Level Rise (SLR) is one of the long term natural hazards that potentially contribute to the mangrove losses (Alongi, 2002).

A sea level rise study conducted by Azura and Hadibah, (2013) in the west coast Peninsular Malaysia based on tidal gauge data showed an increasing trend of mean sea level at all study areas. The affected places were Langkawi, Penang, Lumut, Port Klang, Tanjung Keling and Kukup. Meanwhile, a national finding by Malaysia government agency was stated in National Coastal Vulnerability Index report (DID, 2007). The report identified that the mean sea level at the southern region of Peninsular Malaysia had risen at an average of 1.25mm/yr over 1986 to 2006. These findings showed a strong indication of sea level rise issues and the long term impacts to coastal ecosystem. Marfai and King, (2008) suggested that the long term impacts of untreated SLR problems can combine with other coastal hazards and maximize the damaging effect to coastal communities. Therefore, the mangrove restoration effort should be intensified but not limited to the replanting programme only. The basic understanding on mangrove habitat and its response towards the threat is equally important to ensure the success of the whole conservation strategies. However, according to Ong, (1995) the availability of basic information on local mangrove response to the natural hazards (e.g: SLR) is still poor. Lack of basic information on potential mangrove migration will definitely influence the efficiency of mangroves conservation plan. Hence, through this study, the basic information on local mangrove response to the future SLR is investigated and will provide useful information to strengthen mangrove conservation plans and strategies.

1.3 Study Area

In this study, Pulau Kukup, which is located in Pontian district, Johor, was selected as the site study. Pulau Kukup is an uninhabited mangrove island located 1km offshore from the south – western tip of the state of Johor, Malaysia. It is a small mangrove island surrounded by mudflats with mature mangrove in the interior. Pulau Kukup is a natural mangrove island with six small creeks dissecting the islands in various places. In January 2003, Pulau Kukup was designated as a RAMSAR site by Geneva-Based Ramsar Bureau. The hydrological value of Pulau Kukup is important for flood control and land protection as it shelters the mainland town from severe storm events. It reduces the wave energy reaching Kukup town and helps in stabilizing the shoreline by trapping sediments. The location of the study area was selected based on the physical and ecological features and the importance of Pulau Kukup to local communities.

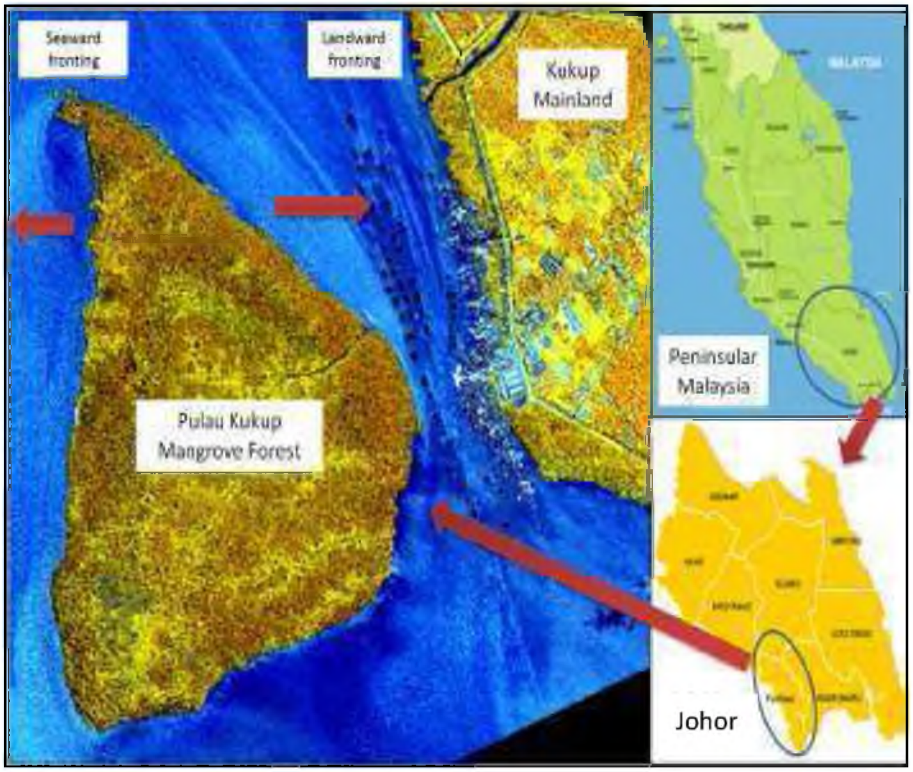

Figure 1.2 Location of the study area

1.4 Objectives of Study

I. To determine the Coastal Vulnerability Index (CVI) of Pulau Kukup due to Sea Level Rise

II. To develop the mangrove vegetation map for Pulau Kukup using World View-2 image

III. To predict the mangrove migration under different Sea Level Rise scenarios for the year 2025, 2050 and 2100

1.5 Scope of Study

The scope of this study can best be described as follows:

I. A review of literatures related to mangrove response to sea level rise, sea level rise scenarios, mangrove characteristics and inundation processes and frequency.

II. Data collection is based on the field survey data and archive records of Pulau Kukup to perform the analysis.

III. Collected data is analyzed through several methodologies. The vegetation map is developed in SPRING 5.2 software based on collected data at the field. The Coastal Vulnerability Index (CVI) is determined based on the methodology adopted in National Coastal Vulnerability Index studies (DID, 2007). The simulation of inundation impacts due to sea level rise is performed in GIS environment (ArcGIS 9.3). In the end, the potential mangrove migration was calculated to represent the effect to the study area.

IV. The determination of mangrove migration in this study is limited to the relationship of tidal inundation changes due to sea level rise with the mangrove zones classification based on Watson, (1928). The final output of this study is in the form of predicted mangrove loss due to SLR, and the mangrove migration map for 2025, 2050 and 2100.

1.6 Significance of Study

The research findings are expected to provide:-

I. The coastal vulnerability index of Pulau Kukup due to Sea Level Rise

II. A vegetation map with mangrove species distribution for Pulau Kukup

III. The migration maps for mangrove zones in 2025, 2050 and 2100 due to selected SLR scenarios (relative, average and worst SLR scenarios)

1.7 Organization of the Thesis

The structure of this thesis as follows:-

I. Chapter 1 will introduce the background of the study, scopes, significance and the objectives of the study.

II. Chapter 2 will be focused on the compilation of general concepts, definition and related issues associated with Sea Level Rise, mangrove response and coastal inundation. This chapter reviews past research on coastal inundation model, physical impacts of Sea Level Rise and the mangrove response to Sea Level Rise.

III. Chapter 3 will explain the methodologies involved for the data analysis. It will give the description of the softwares use (SPRING 5.2, ENVI 4.8 and ArcGIS 9.3), the types of data collections and procedures undertaken to conduct the Coastal Vulnerability Index (CVI) study, the development of vegetation map at the study area using the WorldView-2 image and the strategy to extract the elevation data from IFSAR package. Finally the procedures and calculation method for mangrove migration analysis will also be explained.

IV. Chapter 4 describes the data handling and the manipulation of the raw data for data analysis. The analysis for the CVI study, vegetation map development and mangrove migration analysis will be presented in the chapter.

V. Chapter 5 will discuss the findings from the data analysis. The description will be divided into three parts. They are the discussion on CVI findings, the vegetation map for Pulau Kukup and the discussions on mangrove migration investigation.

VI. Chapter 6 describes the final findings from the research and suggestion for further works.

REFERENCES

Allen, JA, Krauss, KW & Hauff, RD 2003, 'Factors limiting the intertidal distribution of the mangrove species Xylocarpus granatum', *Oecologia,* vol 135, pp.110-121.

Alongi, DM 2002. 'Present state and future of the world's mangrove forests', *Environmental Conservations*, vol 29, pp. 331–349.

Ami, HMD & Kamaludin, MO 2012, 'Sea level change in the Malaysian seas from multi-satellite altimeter data', *International journal of physical sciences*, vol. 7, no. 10, pp. 1694 – 1712.

Andrew, M 1984, 'Charcoal production and leucaena in St. Lucia' in *Watershed management in the Caribbean*, International Institute of Tropical Forestry, Rio Piedras, Puerto Rico, pp. 143-146.

Azura, AR & Hadibah, I 2013, 'Trend analysis of sea level rise for Kukup (Johor) west coast of Peninsular Malaysia' in *International Conference on Emerging Trends in Engineering and Technology (ICETET'2013),* Phuket Thailand, pp.7-18.

Ba, DN & Huong, GT 2012, 'Comparison of elevation derived from InSAR data with DEM from topography map in Son Dong, Bac Giang, Vietnam', in *International Conference on Environmental Science and Technology IPCBEE*, Singapore, pp.25-29

Ball, MC 1988, 'Ecophysiology of mangroves', *Trees*, vol. 2, pp. 129-142.

Bhattacharyya, A 1943, 'On a measure of divergence between two statistical populations defined by probability distributions', *Bulletin of the Calcutta Mathematical Society*, vol. 35, pp. 99–110.

Bins, LS, Fonseca, LMG, Erthal, GJ & Mitsuo, F 1996 'Satellite imagery segmentation: A region growing approach', in *Proceedings of VII Simpósio Brasileiro de Sensoriamento Remote (SBSR),* Salvador, Brazil, pp. 677-680.

Bockelmann, A, Bakker, JP & Neuhaus, R 2002, 'The relation between vegetation zonation, elevation and inundation frequency in a Wadden Sea salt marsh', *Aquatic Botany*, vol. 173, pp. 211–221.

Brunel, C & Sabatier, F 2009, 'Potential influence of sea-level rise in controlling shoreline position on the French Mediterranean Coast', *Geomorphology*, vol.107, pp. 47–57.

Bunt, JS 1996, 'Mangrove zonation: an examination of data from seventeen riverine estuaries in Tropical Australia', *Annals of Botany*, vol. 78, pp. 333-341.

Burgmann, R, Rosen, PA & Fielding, EJ 2000, 'Synthetic aperture radar interferometry to measure earth's surface topography and its deformation', *Annual Review Earth Planet Science*, vol. 28, pp. 169–209.

Burton, IJ, Smith, FJ & Richard SJ 1998, *Handbook on methods for climate change impact assessment and adaptation strategies.* United Nations Environmental Programme (UNEP), New York, pp. 464.

Cade, BS 1997, 'Comparison of tree basal area and canopy cover in habitat models: subalpine forest', *Journal of Wildlife Management*, vol. 61, no.2, pp. 326-335.

Cahoon, DR 2006, 'A review of major storm impacts on coastal wetland elevations', *Estuaries and Coasts*, vol. 29, pp. 889–898.

Camara, G, Souza, RCM & Freitas, UM 1996, 'SPRING: Integrating remote sensing and GIS by object oriented data modelling', *Computers & Graphics*, vol. 20, pp. 395-403.

Carretero, S, Rapaglia, J, Bokuniewicz, H & Kruse, E 2013, 'Impact of sea-level rise on saltwater intrusion length into the coastal aquifer, Partido de La Costa Argentina', *Continental Shelf Research*, vol. 61–62, pp.62–70.

Cazenave, A, Lombard, A, & Lovel, W 2008, 'Oceanography present-day sea level rise: A synthesis', *Geoscience*, vol. 340, pp.761–770.

Chang, B, Guan, J & Aral, MM 2014, 'Modeling spatial variations of sea level rise and corresponding inundation impacts: A case study for Florida, USA', *Water Quality Expo Health*, vol. 6, pp. 39-51.

Chen, WB, Liu, WC & Hsu MH 2007, 'Modeling assessment of a saltwater intrusion and a transport time scale response to sea-level rise', *Journal of Hydrology*, vol. 340, pp. 63-77.

Church, J, McInnes, JK & White, N 2004, 'Sea level rise and the frequency of extreme events around the Australian coastline', in *Coast to Coast '04 – Conference Proceedings, Australia's National Coastal Conference*, Hobart, pp. 1- 8.

Church, JA & White, NJ 2006, 'A 20th century acceleration in global sea level rise', *Geophysical Res Letter*, vol. 33, pp. 353.

Church, JA, Clark, PU, Cazenave, A, Gregory, JM, Jevrejeva, S, Levermann, A, Merrifield, MA, Milne, GA, Nerem, RS, Nunn, PD, Payne, AJ, Pfeffer, PT, Stammer, D & Unnikrishnan, AS 2013, 'Sea level change', in *The physical science basis, fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC),* Cambridge University Press, United Kingdom, pp. 1030 -1137.

Cintrón, G & Schaeffer-Novelli, Y 1984, 'Methods for studying mangrove structure' in *The mangrove ecosystem: research methods*, UNESCO, United Kingdom, pp. 1-251.

Cooper, MJP, Beevers, MD & Oppenheimer, M 2008, 'The potential impacts of sea level rise on the coastal region of New Jersey, USA', *Climate Change*, vol. 90, pp. 475–492.

Dahdouh-Guebas, F & Koedam, N 2006, 'Coastal vegetation and the Asian tsunami', *Science*, vol. 311, pp. 37–38.

Davis, JH 1940, *The ecology and geologic role of mangroves in Florida.* Publications of the Carnegie Institute, Washington.

Delgado, P, Henselb, PF, Jiménezc JA & Day, JW 2001, 'The importance of propagule establishment and physical factors in mangrove distributional patterns in a Costa Rican estuary', *Aquatic Botany*, vol. 71, pp. 157–178.

Deltares, 2015, *Flooding projections from elevation and subsidence models for oil palm plantations in the Rajang Delta peatlands Deltares Report 1207384.* Available from: Wetlands International. [May, 2015]

Department of Survey and Mapping Malaysia 2005, *Garis panduan penggunaan sistem geoid Malaysia (MyGEOID).* Available from: Pekeliling Ketua Pengarah Ukur dan Pemetaan Bil. 10, Tahun, 2005, JUPEM. [6 Sept 2005].

Di-Nitto, D, Neukermans, G, Koedam, N, Defever, H., Pattyn,, F, Kairo, JG & Dahdouh-Guebas, F 2014, 'Mangroves facing climate change: landward migration potential in response to projected scenarios of sea level rise', *Biogeosciences*, vol. 11, pp. 857-871.

DID, 2007, *The National Coastal Vulnerability Index Study-Phase 1 Report.* Available from: Drainage and Irrigation Department (DID), Malaysia. Report submitted by Coastal and Offshore Engineering Institute [December 2007].

Digital Globe, 2009, *Digital Globe Core Imagery Products Guide.* Digital Globe, Longmont Colorado United State.

Duarte, CM, Thampanya, U, Terrados, J, & Miguel, D 1999, 'The determination of the age and growth of SE Asian mangrove seedlings from internodal counts', *Mangroves and Salt Marshes*, vol. 3, pp. 251–257

Duke, N, Ball, M, & Ellison, J 1998, 'Factors influencing biodiversity and distributional gradients in mangroves', *Global Ecology & Biogeography Letters*, vol. 7, pp. 27–47.

Ellison, AM 2002, 'Macroecology of mangroves: large-scale patterns and processes in tropical coastal forests', *Trees*, vol. 16, pp.181–194.

Ellison, AM, Bank, BD, Clinton, EA, Colburn, K, Elliott, CR, Ford, DR, Foster, BD, Kloeppel, JD, Knoepp, GM, Lovett, J, Mohan, DA, Orwig, NL, Rodenhouse, WV, Sobczak, KA, Stinson, JK, Stone, CM, Swan, J, Thompson, B & Webster, JR 2005, 'Loss of foundation species: consequences for the structure and dynamics of forested ecosystems', *Frontiers in Ecology and the Environment*, vol. 9, pp. 479- 486.

Ellison, JC 1993, 'Mangrove retreat with rising sea-level, Bermuda,'*Estuarine, Coastal and Shelf Science,* vol. 37, pp. 75-87.

Ellison, JC 2000, 'How South Pacific mangroves may respond to predicted climate change and sea level rise' in *Climate change of South Pacific: impact and responses in Australia, New Zealand and Small Island States*, Kluwer Academic Publisher, Netherland, pp.289-301.

Ellison, JC & Stoddart, DR 1991, 'Mangrove Ecosystem Collapse during Predicted Sea-Level Rise: Holocene Analogues and Implications. *Journal of Coastal Research,* vol. 7, no. 1, pp. 151-165.

Ellison, JC & Zouh, I 2012, 'Vulnerability to climate change of mangroves: Assessment from Cameroon, Central Africa', *Biology*, vol. 1, pp. 617- 638.

Emery, KO, 1980, 'Relative sea levels from tide-gauge records', in *Proceedings National Academic Science*, Washington, vol. 77, no. 12, pp. 6968-6972.

Ercan, A, Leverent-Kavvas, M & Rovshan, K 2013, '*Long-range dependence and sea level forecasting'*, Springer Briefs in Statistics, Germany.

Espindola, GM, Camara, G, Reis, IA, Bins, LS & Monteiro, AM 2006, 'Parameter selection for region-growing image segmentation algorithms using spatial autocorrelation', *International Journal of Remote Sensing*, vol. 27, no. 14, pp. 3035–3040

Fairbridge, R & Krebs, O 1962, 'Sea level and the Southern Oscillation', *Geophysical Journal of Royal Astronomical Society*, vol. 6, pp.532-545.

Field, CD 1995, 'Journey amongst mangroves' in *International Society for Mangrove Ecosystems*, Okinawa, Japan, pp. 1-140.

Frazier, TG, Wood, N, Yarnal, B & Bauer, DH 2010, 'Influence of potential sea level rise on societal vulnerability to hurricane storm-surge hazards, Sarasota County, Florida', *Applied Geography*, vol.30, pp. 490–505.

Gedan, KB, Matthew, L, Wolanski, E & Barbier EB 2010, 'The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm', *Climatic Change*, vol. 106, pp.7-29.

Gilman, EL, Ellison, J & Coleman, R 2007, 'Assessment of mangrove response to projected relative sea-level rise and recent historical reconstruction of shoreline position', *Environmental Monitoring Assessment,* vol. 124, pp.105–130.

Gilman, EL, Ellison, J & Coleman, R 2008, 'Threats to mangroves from climate change and adaptation options, *Aquatic Botany*, vol.89, no.2, pp.237-250.

Gornitz, V 1991, 'Palaeogeography, palaeoclimatology, palaeoecology', *Global and Planetary Change Section,* vol. 89, pp. 379-398.

Gornitz, V, Lebedeff, L & Hansen, J 1982, 'Global sea level trend in the past century', *Science*, vol. 215, pp.1611-1614.

Gornitz, VM, Beaty, TW & Daniels, RC 1997, *A coastal hazards data base for the U.S. West coast*. Available from: U.S Department of Energy, Environmental Sciences Division. [December, 1997].

Gutenberg, B 1941,'Changes in sea level, postglacial uplift and mobility on the earths interior', *Geological Society of America Bulletin,* vol. 52, pp.721-772.

Hansen, J, Johnson, D, Lacis, A, Lebedeff, S, Lee, P, Rind, D & Russell, G 1981, 'Climate impact of increasing atmospheric carbon dioxide', *Science*, vol. 213, pp.957-966.

Hoozeman, FMJ, Marchand, M & Pennekamp, HA 1993, *Sea Level Rise: A Global Vulnerability Assessment-Vulnerability Assessments for Population, Coastal Wetlands and Rice Production on a Global Scale*, 2nd edn. Delft Hydraulics, Delft, Netherlands.

Huang, X & Morris, JT 2005, 'Distribution of phosphate activitiy in marsh sediment along the estuarine salinity gradient', *Marine Ecology Progress Series*, vol. 292, pp. 75-83.

Intermap Technologies Inc 2010, *Intermap Technologies Handbook*, Intermap Technologies Inc. Colorado, United State, pp. 1-150.

IPCC 2001, Climate *change 2001: The scientific basis*. Cambridge University Press, Cambridge, United Kingdom, pp. 881.

IPCC, 2007, *Climate change 2007: The physical science basis.* Cambridge University Press, United Kingdom. pp.996.

IPCC, 2013, *Climate change 2013: The physical science basis.* Cambridge University Press, Cambridge, United Kingdom. pp. 1535.

Islam, SMR, Huq, S & Ali, A 1999, *Beach erosion in the eastern coastline of Bangladesh,* Kluwer Academic Publishers, Dordrecht, pp. 71-92.

IUCN, 2014, *International Union for Conservation Nature red list.* Available from : <http://www.iucnredlist.org/search> [27 December 2014].

Janousek, CN & Mayo, C 2013, 'Plant responses to increased inundation and salt exposure: interactive effects on tidal marsh productivity', *Plant Ecology*, vol. 214, pp.917–928.

Jawa, RR & Srivastava, PBL 1989, 'Dispersal of natural regeneration in some Piai-invaded areas of mangrove forests in Sarawak', *Forest Ecology Management,* vol. 26, pp.155-177.

Jeofry, MH & Rozainah, MZ 2013, 'General observations about rising sea levels in Peninsular Malaysia', *Malaysian Journal of Science*, vol. 32 (SCS Sp Issue), pp. 363-370.

Joshi, A, Joshi, JR, Shrestha, N, Shrestha, S & Gautham S 2012, ' Object Based Land Cover Extraction Using Open Source Software', *Nepalese Journal on Geoinformatics*, vol. 12, pp.26-30.

Kamaruzzaman, J 2013, 'Malaysian mangrove forests and their significance to the coastal marine environment pollution', *Journal Environment*, vol. 22, pp. 979-1005.

Kathiresan, K & Rajendran, N 2005, 'Coastal mangrove forests mitigated tsunami', *Estuary Coastal Shelf*, vol. 65, pp.601.

Khalid, SM, Umar, MI, Saquib, MS & Asim, AM 2006, 'Bhattacharyya Coefficient in Correlation of Gray-Scale Objects,' *Journal of Multimedia,* vol. 1, no. 1, pp.56-61

Kitaya, Y, Jintana, V, Pinyayotha, S, Jaijing, D, Yabuki, K & Izutani, S 2002, 'Early Development of seven species planted at different elevation in a Thai Estuary', *Tree*, vol.16, pp.150-154.

Kitaya, Y, Suzuki, K, Miyagi, T, Asano, T, Vien, NG & Le, VS 2003, *Growth characteristics of dominantly planted species. Rhizophora apiculata, and microclimate in the mangrove forest in Can Gio District Vietnam, University Annual Report*. Available from: Osaka University Knowledge Archive. [January 2003]

Kjerfve, B 1990, *Manual for investigation of hydrological processes in mangrove ecosystem,* United Nations Educational, Scientific and Cultural Organization (UNESCO), France. pp 79.

Kothari, CR 1990, *Research Methodology Quantitative Techniques*, 2nd edn Vikas Publishing House Pvt. Ltd., New Delhi, pp.401.

Krumme, U. Herbeck, LS & Wang, T 2012, 'Tide and rainfall-induced variations of physical and chemical parameters in a mangrove-depleted estuary of East Hainan (South China Sea)', *Marine Environmental Research* , vol. 82, pp.28-39.

Kuhn, M & Tuladhar, R 2011, 'Visualising the spatial extent of predicted coastal zone inundation due to sea level rise in south-western Australia', *Ocean & Coastal Management*, vol. 54, pp.796-806.

Laben, CA & Brower, BV 2000, *Process for Enhancing the Spatial Resolution of Multispectral Imagery using Pan Sharpening.* U.S. Patent 6011875.

Lemoine, FG, Kenyon, SC, Factor, JK, Trimmer, RG, Pavlis, NK, Chinn, DS,Cox, SM, Klosko, SM, Luthcke, SB, Torrence, MH, Wang, YM,Williamson, RG, Pavlis, EC, Rapp RH & Olson TR 1998, *The Development of the Joint NASA GSFC and the National Imagery and Mapping Agency (NIMA) Geopotential Model EGM96.* Available from: National Aeronautics and Space Administration (NASA), United States. [July, 1998]

Levitus, S, Antonov, JI, Boyer, TP & Stephens, C 2000, 'Warming of the world ocean', *Science*, vol. 287, pp. 2225-2229.

Lisitzin, E 1958, *Sea-level changes, Elsevier Oceanography Series*, Elsevier Scientific Publishing Company. Amsterdam.

Loon, AF, Dijksma, R & Mensvoort, MEF 2007, 'Hydrological classification in mangrove areas: A case study in Can Gio, Vietnam', *Aquatic Botany,* vol. 87 pp. 80–82.

Lu, W, Luzhen, C, Wenqing, W, Nora, F & Guanghui, L 2013, 'Effects of sea level rise on mangrove Avicennia population growth, colonization and establishment: Evidence from a field survey and greenhouse manipulation experiment', *Acta Oecologica*, vol. 49, pp. 83-91.

Luu, QH, Tkalich, P & Tay, TW 2014, 'Sea level trend and variability around the Peninsular Malaysia', *Ocean Scientific Discuss*, vol.11, pp. 1519– 1541.

Maillard, P, Silva, T & David AC 2008, 'An evaluation of Radarsat-1 and ASTER data for mapping Veredas', *Sensors*, vol.8, pp.6055-6076.

Marchisio, G, Padwick, G & Pacifici, F 2011, 'Evidence of improved vegetation discrimination and urban mapping multispectral imagery using World View-2', in *ASPRS 2011, Annual Conference*. Wisconsin, pp. 1-5.

Marfai, M & King, L 2008, 'Potential vulnerability implications of coastal inundation due to sea level rise for the coastal zone of Semarang city, *Indonesia Environmental Geology*, vol. 54, pp.1235–1245.

Marfai, M & King, L 2008a, 'Tidal inundation mapping under enhanced land subsidence in Semarang, Central Java Indonesia', *Natural Hazards*, vol. 44 pp. 93–109.

Maurer, T 2013, 'How to Pan-sharpen images using the Gram-Schmidt pan-sharpen method- A Recipe. in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XL-1/W1, ISPRS Hannover Workshop, Hannover, Germany, pp.139-144

McKee, KL 1993, 'Soil physicochemical patterns and mangrove species distribution—reciprocal effects? ', *Journal Ecology*, vol.81, pp. 477-487.

McLean, R 2009, 'Impacts of weather, climate and sea level-related extremes on coastal systems and low-lying islands' in *Extreme events and Disasters: Managing the Risk*, Cambridge University Press, pp. 435.

Mercer, JB 2001, 'Comparing LIDAR and IFSAR: What can you expect?', in *Proceedings, Photogrammetric Week 2001*, Stuttgart, Germany, pp. 2-10

Milne, GA, Mitrovica, JX & Schrag, DP 2002, 'Estimating past continental ice volume from sea-level data', *Quaternary Science Reviews*, vol. 21, pp.1–3.

Marriotti, G, Fagherazzi, S, Wiberg, PL, McGlathery, KJ, Carniello, L, & Defina, A, 2010, 'Influence of storm surges and sea level on shallow tidal basin erosive processes', *Journal of Geophysical Research*, vol.115, no.11. doi. 10.1029/2009JC005892

Morris, JT, Sundareshwar, PV, Christopher, T & Kjerfve, B 2002, 'Response of coastal wetlands to rising sea level', *Ecology*, vol. 83, no.10, pp. 2869–2877.

Mousavi, M, Jennifer, L, Irish, AE, Frey, N & Francisco, O 2010, 'Global warming and hurricanes: The potential impact of hurricane intensification and sea level rise on coastal flooding', *Climatic Change*, vol. 104, pp. 575-597.

Murali, RM & Dinesh PK 2015, 'Implications of sea level rise scenarios on land use/landcover classes of the coastal zones of Cochin, India', *Journal of Environmental Management*, vol. 148, pp.124-133.

NAHRIM, 2010, *The study of the impact of climate change on sea level rise in Malaysia (Final Report)*. Available from: National Hydraulic Research Institute Malaysia, NAHRIM. [Dec 2010].

Natesan, U & Anita, P 2010, 'The potential impacts of sea level rise along the coastal zone of Kanyakumari District in Tamilnadu, India', *Journal of Coastal Conservation,* vol. 14, no. 3, pp. 207-214.

NOAA, 2010, *Technical considerations for use of geospatial data in sea level: A Change Mapping and Assessment. NOAA Technical Report NOS 2010-01.* Available from: Department of Commerce, NOAA National Ocean Service, Washington [September 2010].

Ng, PKL & Sivatoshi, N 1999, *A Guide to the mangrove of Singapore 1: The Ecosystem and Plant Diversity*, Singapore Science Centre, Singapore, pp.101- 103.

Niang, IE, Mamadou, D & Serigne, F 2010, 'Impacts of climate change on the Senegalese coastal zones: Examples of the Cap Vert Peninsula and Saloum estuary ', *Global and Planetary Change*, vol. 72, pp. 294–301.

Nicholls, RJ 2007, 'The impacts of sea level rise', *Ocean Challenge*, vol. 15, pp. 13–17.

Olievera, BDN, Bello, ORP & Geus, KD 2000, 'Segmentation and classification of Landsat images to monitor the soil use', *International Archives of Photogrammetry and Remote Sensing.* vol. 23, pp. 1065-1072.

Ong, JE 1995, 'The ecology of mangrove management and conservation', *Hydrobiologia*, vol. 295, pp. 343–351.

Ong, JE & Gong, WK 2013, *Structure, Function and Management of Mangrove Ecosystems. ISME Mangrove Educational Book Series No. 2.* International Society for Mangrove Ecosystems (ISME) & International Tropical Timber Organization (ITTO), Yokohama, Japan.

Othman, S 1984, 'Structure of mangrove vegetation at Siar beach, Lundu, Sarawak', *Pertanika*, vol. 7, no. 2, pp. 91-99.

Ozyurt, G & Ergin, A 2009, 'Application of sea level rise vulnerability assessment model to selected coastal areas of Turkey', *Journal of Coastal Research.* vol. 56, pp. 248-251.

Pendleton, EA, Hammar- Klose, ES, Thieler, ER & Williams, SJ 2004, *Coastal vulnerability assessment of Gulf Islands National Seashore (GUIS) to sea-level rise*. United States Geological Survey (USGS), Woods Hole, Massachusetts.

Pilkey, OH & Davis, TW 1987, 'An analysis of coastal recession models' in: *Sea-Level Fluctuation and Coastal Evolution.* Society of Economic Paleontologists and Mineralogists, Oklahoma, pp. 68.

Piou, C, Ilka, CF, Uta, B & Faustino C 2006, 'Zonation Patterns of belizean offshore mangrove forests 41 years after a catastrophic hurricane', *Biotropica*, vol. 38, no. 2, pp. 365–374.

Por, FD 1972, 'Hydrobiological notes on the high-salinity waters of the Sinai Peninsula', *Marine Biology*, vol. 14, pp. 97-111.

Putz, FE & Chan, HT 1986, 'Tree growth, dynamics, and productivity in a mature mangrove forest in Malaysia', *Forest Ecology Management.* vol.17, pp. 211-230.

Rabinowitz, D 1978, 'Early growth of mangrove seedlings in Panama, and an hypothesis concerning the relationship of dispersal and zonation', *Journal of Biogeography*, vol. 5, no. 2 , pp. 113-133.

Rahmstorf, S 2007, *A semi-empirical approach to projecting future lea-level rise*, V*ol 315 Science*. Available from: <www.sciencemag.org> [12December 2014].

Ramsar Convention Bureau 2003, *Information sheet on Ramsar Wetlands (RIS).* Available from : <www.ramsar.org > [13 October 2014]

Ramsay, D 2011, *Coastal erosion and inundation due to climate change in the Pacific and East Timor report.* Available from: National Institute of Water & Atmospheric Research Ltd. [June 2011]

Rao, KN, Subraelu, J & Ajai P 2008, 'Sea-level rise and coastal vulnerability :an assessment of Andhra Pradesh coast, India through remote sensing and GIS', *Journal Coastal Conservation*, vol. 12, pp.195 – 207.

Rapinel, S, Hubert-Moy, L & Clément, B 2014, 'Combined use of LiDAR data and multispectral earth observation imagery for wetland habitat mapping', *International Journal Applied Earth Observation & Geoinformation,* vol. 37, pp. 56-64

Rivera-Monroy, VH, Twilley, RR, Davis, SE, Childers, DL, Simard, M, Chambers, RM, Jaffe, R, Boyer, JN & Rudnick, D 2011, 'The role of the Everglades mangrove ecotone region (EMER) in regulating nutrient cycling and wetland productivity in south Florida', *Critical Reviews in Environmental Science & Technology*, vol. 41, pp. 633– 699.

Saintilan, N Wilson, N, Rogers, K, Rajkaran, A & Krauss, KW 2014, 'Mangrove expansion and salt marsh decline at mangrove poleward limits', *Global Change Biology*, vol. 20, no. 1, pp.147-157.

Salehi, B, Zhang, Y, Zhong, M & Dey, V 2012, 'Object-based classification of urban areas using VHR imagery and height points ancillary data', *Remote Sensing*, vol. 4, pp. 2256-2276.

Sarkar, M. Kabir, R & Ara, B 2014, 'Impacts of and adaptations to sea level rise in Malaysia', *Asian Journal of Water, Environment and Pollution*, vol. 11, no. 2, pp. 29–36.

Satyanarayana, B, Raman, AV, Frank, D, Kalavati, C & Chandramohan, P 2002, 'Mangrove floristic and zonation patterns of Coringa, Kakinada Bay, East Coast of India', *Wetlands Ecology and Management*, vol.10, pp.25–39.

Semeniuk, V 1980, 'Mangrove zonation along an eroding coastline in King Sound, north-western Australia', *Journal Ecology*, vol. 68, pp.789-812.

Sherrod, CL, & McMillan, C 1985, 'The distributional history and ecology of mangrove vegetation along the northern Gulf of Mexico coastal region', *Contributions in Marine Science*, vol. 28, pp. 129-140.

Silvius, MJ, Chan, HT & Ibrahim, S 1987, *Evaluation of wetlands of the West Coast of Peninsular Malaysia and their importance for natural resource conservation*, WWF-Malaysia, Kuala Lumpur, Malaysia, pp.264.

Simav, O, Şeker, DZ & Gaziolgu, C 2013, 'Coastal inundation due to sea level rise and extreme sea state and its potential impacts: Çukurova Delta case', *Turkish Journal Earth Science*, vol. 22, pp. 671-680.

Snedaker, S 1995,'Mangroves and climate change in the Florida and Caribbean region: scenarios and hypotheses', *Hydrobiologia*, vol. 295, pp. 43-49.

Snoussi, M, Tachfine, O & Sada, N 2008, 'Vulnerability assessment of the impact of sea-level rise and flooding on the Moroccan coast: The case of the mediterranean eastern zone estuarine', *Coastal and Shelf Science,* vol.77, pp. 206-213.

Soares, MLG 2009, 'A conceptual model for the response of mangrove forests to sea level rise', *Journal of coastal research*, vol. 56, pp. 267 – 271.

Solomon, S, Quin, D, Manning, M, Chen, Z, Marquis, M, Averyt, KB, Tignor, M & Miller, HI 2007, *Climate change 2007: The physical science basis.* Cambridge University Press, Cambridge, United Kingdom.

Suarez, N & Medina, E 2008, 'Salinity effects on leaf ion composition and salt secretion rate in *Avicennia germinans* (L.) L. Braz', *Journal Plant Physiology*, vol. 20, no. 2, pp.131-140.

Sujahangir, M, Kabir, S, Rawshan, A & Yusof, MS 2014, 'Impacts and adaptations to sea level rise in Malaysia', *Asian Journal of Water, Environment and Pollution*, vol. 11, no. 2, pp. 29–36.

Thieler, ER & Hammar-Klose, ES 2000, *National assessment of coastal vulnerability to future sea-level rise: Preliminary results for the US Gulf of Mexico coast. Open-File Report,* United States Geological Survey (USGS), United States, pp.179.

Thomas, R, Rignot, H, Casassa G & Kanagaratnam, P 2004, 'Accelerated sea level rise from West Antarctica', *Science*, vol. 306, pp.255–258.

Thompson, CM & Frazier, TG 2014, 'Deterministic and probabilistic flood modeling for contemporary and future coastal and inland precipitation inundation', *Applied Geography*, vol. 50, pp.1-14.

Thorarinsson, S 1940, 'Present glacier shrinkage and eustatic change in sea level', *Geographical Analysis*, vol. 22, pp.131-159.

Tian, B, Liquan, Z, Xiangrong, W, Yunxuan, Z & Wen, Z 2010, 'Forecasting the effects of sea-level rise at Chong Ming Dongtan Nature Reserve in the Yangtze Delta, Shanghai, China', *Ecological Engineering*, vol. 36, pp.1383–1388.

Titus, JG 1991,'Greenhouse effect and sea-level rise: potential loss of land and the cost of holding back the Sea', *Coastal Management*, vol.19, pp.171-204.

Tomascik, T, Mah, AH, Nontyi, A & Moosa, MK 1997, *The Ecology of the Indonesian Seas (Part 2),* Periplus Edition (HK) Ltd, pp. 1- 950p.

Tomlinson, PB 1986, *The botany of mangroves: Tropical Biology Series*, Cambridge University Press, pp. 1-413.

Tsai, VJ 1993, 'Delaunay triangulations in TIN creation: an overview and a linear-time algorithm', *International Journal of Geographical Information Science*, vol. 7, no.6, pp. 501 – 524.

Twilley, RR, Victor, H, & Ronghua, C 1999, 'Adapting an ecological mangrove model to simulate trajectories in restoration', *Ecology Marine Pollution Bulletin*, vol. 37, pp.404–419.

UNEP 2004, *Mangroves in the South China Sea.* Available from: United Nations Environments Programme (UNEP). [January 2004].

Valiela, I, Jeniffer, L & Bowen, JK 2001, 'Mangrove forests: one of the world threatened major tropical environments', *BioScience*, vol. 51, pp.795-807.

Verma, OP, Madasu, H, Seba, S & Muralidhar, K 2011, 'A simple single seeded region growing algorithm for color image segmentation using adaptive thresholding', in *International Conference on Communication System and Network Technologies*, India, pp. 500-503.

Vermeer, M & Rahmstorf, S 2009, 'Global sea level linked to global temperature', in *Proceedings of the National Academy of Sciences*, United States, vol. 106, no. 51, pp. 21527- 21532.

Wanjiru, MW 2011, *Current status, Utilization, succession and zonation of mangrove ecosystem along Mida Creek, Coast province, Kenya.* Master thesis, Kenyatta University, Kenya.

Ward, PJ, Marfai, MA, Yulianto, F & Hizbaron, DR 2010, 'Coastal inundation and damage exposure estimation: a case study for Jakarta', *Natural Hazard*, vol. 56, pp. 899-916.

Watson, JG 1928, *Mangrove forests of the Malay Peninsula*, Fraser and Neave, Singapore.

Whiteside, T & Ahmad, W 2005, 'A comparison of object-oriented and pixel-based classification methods for mapping land cover in northern Australia', in *Proceedings of SSC2005 Spatial intelligence, innovation and praxis: The national biennial Conference of the Spatial Sciences Institute*, Melbourne, pp. 2-9.

Wightman, G 2006, *Mangroves of the northern territory, Australia: Identification and traditional use*, Department of Infrastructure, Planning and Environment, Australia.

Willis, JK, Don, P, Chung-Yen, K & Shum SK 2008,' Global sea level rise recent progress and challenges for the decade to come', *Oceanography*, vol.23, no.4, pp. 26-35

Wilton, K 2002, *Coastal wetland habitat dynamics in selected New South Wales estuaries*. Ph.D. thesis, Australian Catholic University, Fitzroy, Australia.

Woodroffe, CD 1985, 'Studies of a mangrove basin, Tuff Crater, New Zealand: Comparison of volumetric and velocity- area methods of estimating tidal flux', *Estuarine Coastal & Shelf Science*, vol. 20, pp. 431- 445.

Woodroffe, CD 1990, 'The impact of sea-level rise on mangrove shorelines', *Progress in Physical Geography*, vol.14, pp.483 - 487.

Woodworth, PL & David, LB 2004, 'Evidence for systematic changes in extreme high waters since the mid-1970s', *Journal Climate*, vol. 17, pp.1190–1197.

Yang, SC, Shang, S & Gwo, WH 2013, 'The salinity gradient influences on the inundation tolerance thresholds of mangrove forests', *Ecological Engineering*, vol. 51, pp. 59– 65.

Yang, Z, Taiping, W, Ruby, L, Kathy, H, Tony, J, Ian, K, Jennie, R, Benjamin, P & Tom, W 2014, 'A modeling study of coastal inundation induced by storm surge, sea-level rise, and subsidence in the Gulf of Mexico', *Natural Hazards,* vol. 71. pp.1771–1794.

Yates, ML, Le-Cozannet, G & Lenôtre, N 2011, 'Quantifying errors in coastal erosion and inundation hazard assessments. *Journal of Coastal Research*, vol. 64, pp. 260-264

Yoskowitz, DW, James, G & Ali M 2009, *The socio-economic impact of sea level rise in the Galveston bay region*, Environmental Defense, Texas, United State.

Yulianto, E, Sukapti, WS, Rahardjo, AT, Siregar, DA & Suparan, PK 2004, 'Mangrove shoreline responses to Holocene environmental change, Makassar Strait, Indonesia', *Review of Palaeobotany and Palynology*, vol. 131, pp. 251–268.