ASSESSMENT OF COASTAL VULNERABILITY TO SEA LEVEL RISE OF BOLINAO, PANGASINAN USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS

S. R. C. Reyes [a, *], A. C. Blanco [b],

[a] Graduate Student, Environmental Systems Applications of Geomatics Engineering (EnviSAGE) Laboratory, Department of Geodetic Engineering, University of the Philippines, Diliman, Quezon City 1101 Philippines – sherylrose.reyes@gmail.com

[b] Assistant Professor, Environmental Systems Applications of Geomatics Engineering (EnviSAGE) Laboratory, Department of Geodetic Engineering, University of the Philippines, Diliman, Quezon City 1101 Philippines – ayeh75@yahoo.com

KEY WORDS: Climate Change, Sea Level Rise, Vulnerability, Coast, Laser Scanning, GIS

ABSTRACT:

A number of studies assessing the vulnerability of Southeast Asia to climate change have classified the Philippines as one of the vulnerable countries in the region. Bolinao, Pangasinan is a municipality located in northwestern Luzon, situated in the western part of the Lingayen Gulf and is bounded on the north and west by the South China Sea (West Philippine Sea). Recent studies have verified the varying trends in sea level across the South China Sea, which is considered as one of the largest, semi-enclosed marginal seas in the northwest Pacific Ocean. Three barangays (villages) were included in the study: (1) Luciente 1.0, (2) Concordia and (3) Germinal. The Socioeconomic Vulnerability Index (SVI) was computed based on population, age, gender, employment, source of income and household size, which were gathered through a qualitative survey in the selected barangays. The Coastal Vulnerability Index (CVI) described the physical vulnerability of these coastal communities based on recorded sea level anomalies and significant wave heights of multiple satellite altimetry missions, coastal topography derived from the 25-m SRTM digital elevation model (DEM), bathymetry from WorldView-2 and additional elevation data from terrestrial laser scanning surveys. The research utilized merged satellite altimetry data downloaded from the Radar Altimetry Database System (RADS), which covered the period from 1991-2010. The SVI and CVI were calculated and evaluated in ArcGIS. The SVI and CVI were integrated to determine the Total Vulnerability Index (TVI), which characterized the vulnerability of the three barangays in five classes, from very low to very high vulnerability.

1. INTRODUCTION

1.1 Background of the Study

The Philippine archipelago has a huge aggregate coast of approximately 32,400 kilometers and the majority of its continuously growing population resides on coastal plains, making it vastly vulnerable to the effects of accelerated sea level rise (Capili, Ibay, & Villarin, 2005). The Philippine coasts are clustered with communities living along the shores and families whose livelihood depends largely on coastal resources.

The impact of sea-level rise as one of the major effects of climate change has been the focus of numerous studies on marine habitats and human settlements along the coast. Projections by the Intergovernmental Panel on Climate Change (IPCC) approximated that sea level is rising globally at about 13 to 94 centimeters by 2100 as a result of the ocean thermal expansion and the melting of ice caps (IPCC, 2001). Geological and tide gauge data supply historical evidences of sea level rise during the 19th and 20th centuries, estimating an average rate of 1.7 millimeters per year during the 20th century (Church et al., 2008).

Coastal vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes (Hinkel & Klein, 2006).One of the most widely index in risk and vulnerability assessments of coastal communities to sea level rise is the Coastal Vulnerability Index (CVI) developed by Gornitz et al. (1994 as reviewed by (Doukakis, 2005)). The CVI utilizes physical and geological variables to be related in a quantifiable manner that characterizes the relative vulnerability of the coast to physical changes due to future sea level rise (Dwarakish et al., 2009). Moreover, the development of a Socioeconomic Vulnerability Index (SVI), which is dependent on the locally relevant socioeconomic factors, can further quantify the degree of vulnerability. The integration of these indices may provide a merged vulnerability index resulting to the Total Vulnerability Index (TVI) that characterizes the overall risk and vulnerability of the coastal communities (Szlafsztein & Sterr, 2007). Most of the studies using these

---

* Corresponding author. This is useful to know for communication with the appropriate person in cases with more than one author.

indices have used low resolution digital elevation models (DEM) and are either presented at the global or regional scale.

The research aims to assess the vulnerability of Philippine coasts to sea level rise, at a regional scale, by verifying rates of sea level fluctuations and examining its spatial variability in Philippine waters, particularly in the coastal communities of Bolinao, Pangasinan. This study will also investigate the primary conditions that characterize the susceptibility of the natural system and of coastal societies (persons, groups or communities) to coastal hazards, which are potentially aggravated by climate change. The study aims to utilize the established techniques in remote sensing (RS) and geographic information systems (GIS) to provide baseline information about the possible threats brought about by climate change. The research will provide an integrated vulnerability assessment, which includes both physical and socioeconomic parameters, at a *barangay* (village) scale, taking into account the local hazards and existing characteristics of the coastal communities.

The research is significant in view of the lack of sufficient information on sea level rise and their impacts on coastal communities. Such information are critically required by policy makers, coastal managers and residents of the coastal zone in order to formulate effective and efficient policies and measures related to climate change adaptation.

1.2 Climate Change Studies in the Philippines

The Philippines is comprised of 7,100 islands and a significant fraction of its population is living near the shore. Despite the possible risks and threats posed by climate change, the population of people living near the coast continues to rise. The residents of these coastal communities are highly dependent on coastal resources and whose primary sources of income may come from fishing, seaweed farming, mangrove lumber, harvesting of sea shells (both for food and commercial purposes), aquaculture businesses and many other businesses related to marine resources. The Philippine coral reefs is the source of the nation's annual economic benefits of about US$1.1 billion per year (Capili et al., 2005). The effects of climate change can threaten these coastal societies, but only a few studies are focused on assessing the vulnerability of the coastal communities in the Philippines. Existing researches are oriented towards the preservation of coastal habitats and protection of the marine environment, and only a few are centered on determining the hazards of climate change to these coastal communities and in formulating possible strategies for adaptation.

A simple yet comprehensive compilation of climate change studies in the Philippines emphasizes the potential effects of rising sea levels (Capili et al., 2005). Sea level rise may lead to inundation, erosion, tidal variations, alterations in ocean dynamics, salt water intrusion in estuaries and rivers, reduced productivity of seagrass beds and decreased yields in mangrove lumber. The predicted global sea level rise from 1990 to 2100 is approximately 0.09 – 0.88 meters (IPCC, 2001), which can lead to coastal erosion and increased susceptibility to storm surges, particularly in the Eastern Philippines.

A vulnerability assessment of Northern Navotas, a densely populated area in Metro Manila, was carried out by using

existing spatio-temporal datasets and by utilizing 3D visualization software and GIS (Galgana, Abad, Villarin, & Vicente, 2004). Future simulations and modelling provided an in-depth visualization of inundation areas for sea level rise scenarios from 0.25 meters to 1.75 meters. By implementing these techniques, researchers can accurately specify flood-prone areas and a more efficient mobilization for disaster mitigation and adaptation strategies may be implemented by the local government and social welfare organizations. A rapid decrease in land area as sea level rises was evident in the 3D visualization of incremental sea level rise projections.

One of the early projections of sea level rise for the Philippines can be found in a leaflet produced for the World Wildlife Fund (WWF) to illustrate the various climate change scenarios and to visualize the differences among the seven global climate models proposed by the IPCC (Hulme & Sheard, 1999). The Global Sea Level Observing System (GLOSS) is maintaining tide stations in Manila and Legaspi. Both tide stations recorded a small rise in relative sea level before the 1960s and a gradual increase of about 20 – 40 centimeters to the present. The increase in sea level may partially be attributed to excessive land reclamation and subsidence, and the residuals are probably caused by the globally increasing sea surface temperatures and melting glaciers. A significant finding of this brief investigation is the high correlation in the expansion of warmer ocean water and increasing sea levels. The 2080 projection of 100-centimeter rise in sea level of the A2-high scenario predicts that about 5,000 hectares of the Manila bay area will be regularly inundated and about 2.5 million residents will be affected. An anticipated 30-centimeter rise by the year 2045 is demonstrated in the B2-mid and A1-mid scenarios, consequently flooding about 2,000 hectares of land in the Bay area and displacing about 0.5 million individuals.

Despite the archipelagic characteristics of the Philippines and its vulnerability to the effects of climate change, only a few studies on the vulnerabilities of human settlements along the coast had been carried out. With the effects of climate change becoming more pronounced in the past years, it is very important for the nation to focus on determining priority areas for climate change adaptation.

1.3 Study Area

This study investigates the vulnerability to sea level rise of *barangays* (villages) Luciente 1.0, Germinal and Concordia. The *barangay* is the smallest administrative division in the Philippines.

Geographical Location: Bolinao, Pangasinan (Figure 1) is a 3rd class municipality and a First Congressional District located on the cape of the western part of Lingayen Gulf. It is situated along the latitude 16° 16' to 16° 26' and longitude 119° 45' to 119° 57', with an approximate land area of 23,320 hectares. Bolinao is bounded by the South China Sea (West Philippine Sea) on the north and west; on the east by the Caquiputan Channel, which also separates the municipality from the island municipality of Anda, Pangasinan; and on the south by the municipality of Bani, Pangasinan.

Population: Bolinao's has a population of 69,568 based on the 2007 census made by the National Statistics Office. The municipality's population growth rate is approximately 2.16

percent, based on the census records from 1960 to 2007, as compared to the provincial population growth rate of about 1.33 percent.

Figure 1. The study area.

Topography: The topography of Bolinao is characterized mainly by flat to rolling with some steep areas, particularly along the shorelines of the western part of the municipality, near the Caquiputan channel and several areas of Santiago Island.

Geological Characteristics: The geological characteristics of the municipality are classified into three major categories: (1) Alluvium, (2) Coralline Limestone, and (3) Sandstone and Shale. Barangays Patar, Ilog-Malino, Estanza, Balingasay, Arnedo, Concordia, Lambes, Catungi, Culang, Luna, Luciente II and a significant portion of the Santiago Island are classified under the first category and can be further be classified either Active Tidal Flats (ATF) and Former Tidal Flats (FTF). Coralline limestone is found in some areas of barangays Lambes, Zaragoza and Catungi. The rest of the municipality is categorized as Sandstone and Shale, with the exception of Santiago Island.

Livelihood: Bolinao is known for its abundant aquamarine resources. Majority of its continuously growing population depend on these natural resources for their livelihood. Healthy coral reefs found in the municipal waters serve as habitats for fishes and other marine animals. The high number of fishes caught within the municipal waters of Bolinao supplies the needs of the eastern part of the province, nearby provinces and Metro Manila. Aquaculture businesses, which include fish ponds and sea water farms, are also maintained in the various parts of the municipality. Bolinao's primary sources of income include farming and fishing. Fishing activities include fish capture and aquaculture. Small-scale and cottage industries also include shell crafts and dried fish making.

Environmental Threats: Bolinao is threatened by both natural and man-made risks. Natural risks include earthquakes,

tsunamis, landslides and strong typhoons. Man-made threats include oil and coal spills and those arising from anthropogenic activities like harmful algal blooms and fish kills.

2. DATA AND METHODOLOGY

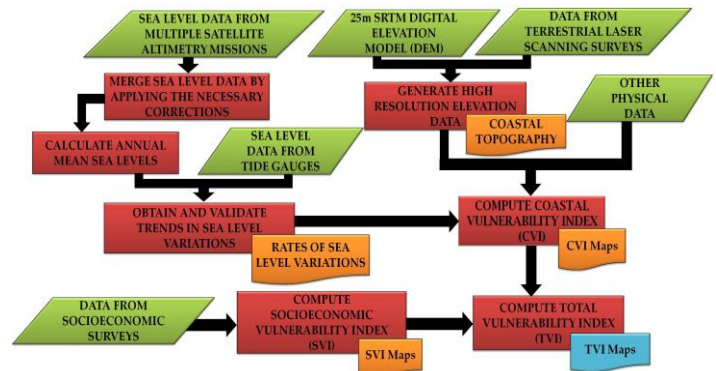### 2.1 Conceptual Framework

Figure 2. The vulnerability assessment methodology.

The study is comprised of four major stages (Figure 2): (1) Sea level rise assessment using recorded sea level anomalies from multiple satellite altimetry missions; (2) Socioeconomic data gathering and analysis; (3) Derivation of high resolution digital elevation model (DEM) and digital surface model (DSM) from high resolution satellite images and terrestrial laser scanning surveys, and (4) Data integration in GIS.

2.2 Sea Level Rise Assessment

Sea level anomaly data from six (6) satellite altimetry missions, namely, ERS-1, ERS-2, Envisat 1, TOPEX/POSEIDON, JASON-1 and JASON-2 were downloaded from the Radar Altimetry Database System (RADS, rads.tudelft.nl). This online database is maintained by the Delft Institute of Earth-Oriented Space Research (DEOS) of the Delft University of Technology (RADS, rads.tudelft.nl).

The records downloaded cover the period from 1991 to 2010. Corrections applied (Trisirisatayawong, Naeije, Simons, & Fenoglio-Marc, 2011) include dry troposphere, wet troposphere, ionosphere, dynamic atmosphere, ocean tide, load tide, solid earth tide and pole tide sea state bias. Reference frame biases and altimeter land flags based on a 2' x 2' mask were also applied. The DNSC08 was used as the mean sea surface.

Tide gauge records were also obtained from the Oceanography Division of the National Mapping and Resource Information Authority (NAMRIA). Records from the Manila South Harbor, La Union, Subic Bay, Currimao, Puerto Princesa and Occidental Mindoro stations were included in the evaluation of Mean Sea Level (MSL).

2.3 Socioeconomic Data Gathering

A 3-page questionnaire was distributed to selected households in the study area. The questionnaires include inquiries about population, education, primary sources of income, migration, flooding history, typhoon frequency, property damage after

typhoon and flooding events, repair of properties and environmental awareness.

These questions aim to collect demographics data and information based on experience since most of the residents have been living in the area for generations (Mimura, 1999) to fill in the gaps needed to conduct an in-depth vulnerability assessment.

2.4 Detailed Coastal Topography

The DLR Earth Observation Center released the digital elevation models (DEMs) generated from the X-band data of the Shuttle Radar Topography Mission (SRTM). A pixel of this DEM approximately corresponds to an area of 25 m x 25 m on the ground. The elevation values are provided with an elevation accuracy of about 1 meter. The horizontal accuracy is ±20 m (abs.) / ±15 m (rel.), both 90% CE and the vertical accuracy is ±16 m (abs.) / ±6 m (rel.), both 90% LE (DLR/ASI, 2011).

To further improve the vulnerability assessment, profiles of the structures along the coast were obtained by conducting terrestrial laser scanning surveys using Leica ScanStation 2 at specific segments of the study area.

Bathymetry data will be extracted from the WorldView-2 image of Bolinao, Pangasinan taken last March 2010. According to some studies (Lee, Kim, Olsen, & Kruse, 2011; Madden, 2011), the Yellow and Green bands can provide the best bathymetric data for a depth range of 2.5 – 20 meters.

2.5 Data Integration in ArcGIS

The physical and socioeconomic vulnerabilities characterized by the parameters collected from various field surveys will be combined and assessed using ArcGIS 10. The Analytical Hierarchical Process (AHP) will be used to determine the individual importance of physical and socioeconomic variables. The physical vulnerability will be represented by the CVI and the socioeconomic vulnerability will be described by the SVI. Weights will be applied to the parameters to rank their contributions to the overall vulnerabilities. The Total Vulnerability Index (TVI) will be obtained to verify the susceptibility of the communities in terms of both the natural and socioeconomic aspects.

3. PRELIMINARY RESULTS

3.1 Assessment of Sea Level Variability

Mean Sea Level (MSL) Records from Tide Gauges:

Due to the lack of sufficient data from the tide stations nearest the study area, several tide stations were evaluated. The Manila South Harbor station has the longest record of over 60 years (Figure 3). The records show that sea level is continuously increasing since 1964.
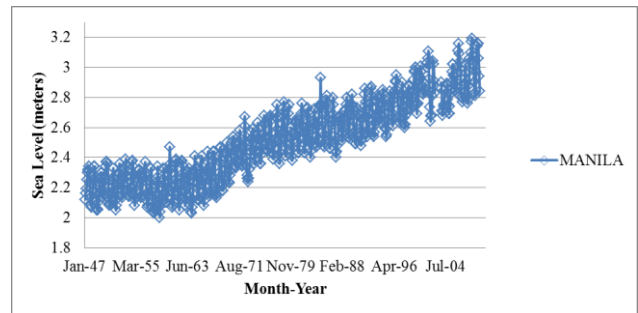
Figure 3. Monthly sea level records at the Manila South Harbor station.

The tide stations located at San Jose, Puerto Princesa and San Fernando (Figure 4) were active only for the past 20 years. San Jose and Puerto Princesa show a slowly increasing rise in sea level values. Data gaps are evident in the San Fernando station, which may be attributed to some operational difficulties.
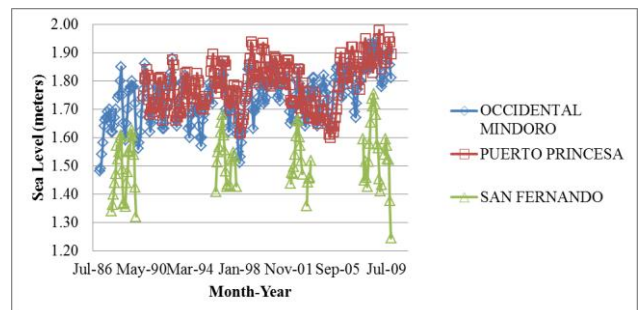
Figure 4. Monthly sea level records at the San Jose, Occidental Mindoro, Puerto Princesa, Palawan and San Fernando, La Union stations.

The Currimao and Subic stations (Figure 5) are also very near the study area. However, these tide stations are relatively new and were recording sea level values for several years only. The plot shows significant peaks when sea level rises.
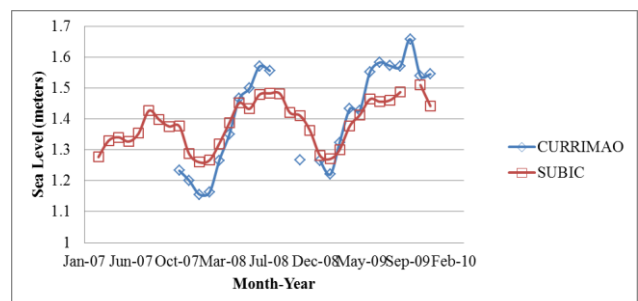
Figure 5. Monthly sea level records at the Currimao, Ilocos Norte and Subic Bay, Zambales stations.

Sea Level Variability from Merged Satellite Altimetry:

Merged satellite altimetry data provide an overview of the sea level variations for about a period of two decades (Figure 6). Sea level anomalies recorded in Bolinao show that sea levels are continuously fluctuating, but higher values are observed during sea level rise compared to values of sea level fall.
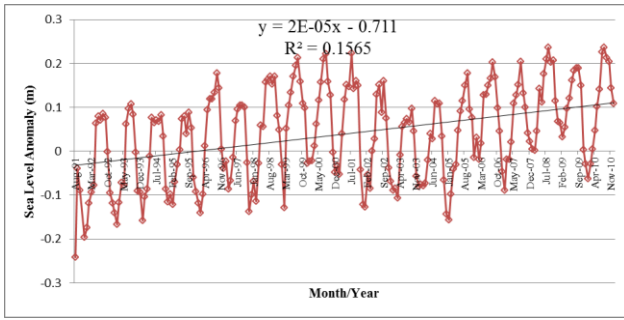
Figure 6. Monthly sea level anomaly averages obtained from merged altimetry missions from 1991 to 2010. The monthly records indicate a rising trends in sea level.

To further illustrate the sea level variations, sea level anomaly contour maps were generated for the years 1991, 2000 and 2010 (Figure 7). These maps indicate significant differences in the sea level anomaly trends and indicate a rise in sea level.
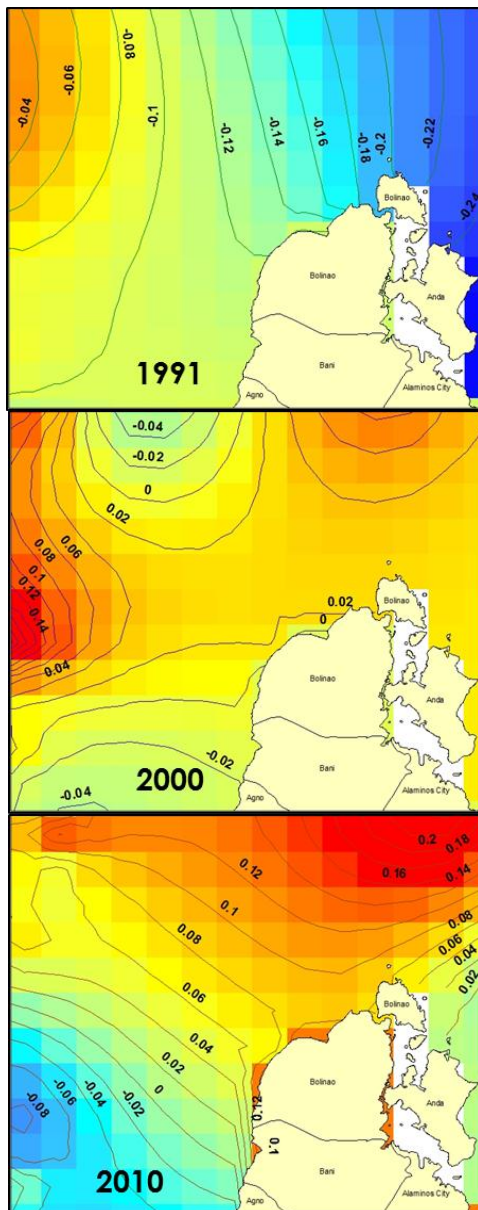

Figure 7. Contour maps of sea level anomalies for 1991 (top), 2000 (middle) and 2010 (bottom).

3.2 Statistics from Socioeconomic Data Gathering

The socioeconomic data gathered from the three barangays indicated that more than 20% of the recorded population live near the coasts (**Figure 8**). Most of these families rely on fishing and fish-related businesses (**Figure 9**).
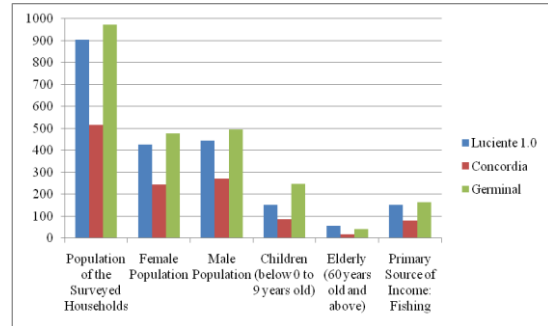

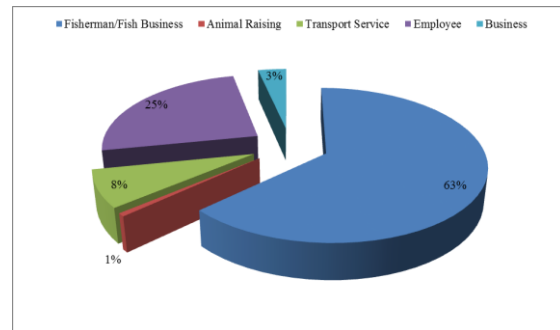Figure 8. The population statistics of the three barangays.

Figure 9. The percentage of the primary sources of income in the three barangays.

Flooding is experienced in some areas due to higher high tides, runoff, huge waves and stronger typhoons. The families experience damage to their properties after the typhoon and flooding events. Most of them were able to recover over a short span of time; however, some property damages cannot be repaired but must be replaced or rebuilt, which have higher costs that most of the residents cannot afford.

Children below 9 years and elders with age 60 and above represent a significant fraction of the population. Most of the women living in these barangays are housewives. These characteristics of the population can lead to a higher vulnerability to the potential effects of sea level rise.

4. CONCLUSIONS

The surveys carried out in the study area have verified the potential risks to future sea level rise of the coastal communities located in the three barangays. The susceptibility of these communities to the possible effects of sea level rise extends to their properties and livelihood. The experience-based data can provide researchers with additional information that are not available.

The merged data obtained from several altimetry missions provide an effective scheme of analyzing sea level variations over a long period of time. Comparison of the altimetry data

with the tide gauge records can provide further information on sea level variability.

5. WORK IN PROGRESS

The generation of the detailed coastal topography is important in this study. The elevation profile of the study area is being created by combining the information that can be derived from the SRTM DEM, terrestrial laser scanning data and the shallow water bathymetry extracted from WorldView-2.

The weights of the variables to be used for the calculation of the CVI and SVI are currently being determined through expert judgment. Also, the final equations and GIS methods that will best characterize the vulnerability of the study site are being tested.

7. REFERENCES

References from Journals:

Capili, E. B., Ibay, A. S., & Villarin, J. R. T. (2005). Climate Change Impacts and Adaptation on Philippine Coasts. *Oceans, 3*, 2299-2306. doi: 10.1109/OCEANS.2005.1640108

Church, J. A., White, N. J., Aarup, T., Wilson, W. S., Woodworth, P. L., Domingues, C. M., . . . Lambeck, K. (2008). Understanding global sea levels: past, present and future. *Sustainability Science, 3*, 9-22. doi: 10.1007/s11625-008-0042-4

Doukakis, E. (2005). Coastal Vulnerability and Risk Parameters. *European Water, 11/12*, 3-7.
Dwarakish, G. S., Vinay, S. A., Natesan, U., Asano, T., Kakinuma, T., Venkataramana, K., . . . Babita, M. K. (2009). Coastal vulnerability assessment of the future sea level rise in Udupi coastal zone of Karnataka state, west coast of India.

Ocean & Coastal Management, 52, 467-478. doi: 10.1016/j.ocecoaman.2009.07.007

Galgana, G. A., Abad, S. I. C., Villarin, J. R. T., & Vicente, M. C. T. M. (2004). Visualizing Sea Level Rise in Navotas by GIS and Terrain Modeling. *Journal of Environmental Science and Management, 7*(1), 1-9.

Hinkel, J., & Klein, R. J. T. (2006). Integrating Knowledge for Assessing Coastal Vulnerability to Climate Change. In L. McFadden, R. J. Nicholls & E. C. Penning-Rowsell (Eds.), *Managing Coastal Vulnerability: An Integrated Approach*. Amsterdam, The Nehterlands: Elsevier Science.

Hulme, M., & Sheard, N. (1999). Climate Change Scenarios for the Philippines. Norwich, UN: Climatic Research Unit

Mimura, N. (1999). Vulnerability of island countries in the South Pacific to sea level rise and climate change. *Climate Research, 12*, 137-143.

Szlafsztein, C., & Sterr, H. (2007). A GIS-based vulnerability assessment of coastal natural hazards, state of Pará, Brazil. *Journal of Coastal Conservation, 11*, 53-66. doi: 10.1007/s11852-007-0003-6

Trisirisatayawong, I., Naeije, M., Simons, W., & Fenoglio-Marc, L. (2011). Sea level change in the Gulf of Thailand from GPS-corrected tide gauge data and multi-satellite altimetry. *Global and Planetary Change, 76*(3–4), 137-151. doi: 10.1016/j.gloplacha.2010.12.010

References from Other Literature:

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. In J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. Van der Linden, X. Dai, K. Maskell & C. A. Johnson (Eds.), (pp. 881). Cambridge, United Kingdom and New York, USA: Cambridge University Press.

Lee, K. R., Kim, A. M., Olsen, R. C., & Kruse, F. A. (2011). Determination of bottom-type and bathymetry using WorldView-2.

Madden, C. K. (2011). Contributions to Remote Sensing of Shallow Water Depth with the WorldView-2 Yellow Band. Master of Science in Physical Oceanography and Master of Science in Meteorology, Naval Postgraduate School, Monterey, California.

References from Websites:

DLR/ASI (Producer). (2011, September 25, 2011). DLR SRTM Readme. Retrieved from https://centaurus.caf.dlr.de:8443/eoweb-ng/licenseAgreements/DLR_SRTM_Readme.pdf