REMOTE SENSING AND GIS-BASED ASSESSMENT OF COASTAL VULNERABILITY OF BOLINAO, PANGASINAN TO SEA LEVEL RISE

Sheryl Rose C. Reyes[*1] and Ariel C. Blanco[2]
[1]Graduate Student, Department of Geodetic Engineering, University of the Philippines
Diliman, Quezon City, Philippines; Tel: +63-981-8500#3124
Email: sheryl0724@yahoo.com

[2]Assistant Professor, Department of Geodetic Engineering, University of the Philippines
Diliman, Quezon City, Philippines; Tel: Tel: +63-981-8500#3124
E-mail: ayeh75@yahoo.com

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ABSTRACT: Recent studies have classified the Philippines as one of the many Asian countries that are highly vulnerable to the major effects of climate change. A number of investigations using satellite altimetry data verified the varying trends in sea level across the South China Sea, which is one of the largest semi-enclosed marginal seas in the northwest Pacific Ocean. Bolinao, Pangasinan, a province situated in northwestern Luzon and comprised of several coastal communities, is bounded on the west by the South China Sea. An integrated vulnerability assessment is carried out to quantify the degree of risks and the possible effects of sea level rise to these coastal communities. Three barangays (villages) were examined in this study, namely, Luciente 1.0, Germinal and Concordia. The socioeconomic vulnerability is represented by the Socioeconomic Vulnerability Index (SVI), which is calculated based on population, age, gender, employment, source of income and household size collected through a qualitative survey. The physical vulnerability is described by the Coastal Vulnerability Index (CVI), which is computed based on recorded sea level anomalies from multiple satellite altimetry missions, coastal topography extracted from high resolution satellite images and terrestrial laser scanner data, tidal range, significant wave heights and geomorphology. This study utilized merged satellite altimetry data from the ERS-1, ERS-2, ENVISAT, Jason-1, Jason-2 and TOPEX/POSEIDON missions obtained from the RADS database system, where the necessary corrections were applied accordingly. The results of the merged satellite altimetry data analysis provide a more accurate assessment of sea level trends. The SVI and CVI are calculated by applying weights on the variables and are evaluated in ArcGIS. The SVI and CVI are integrated to obtain the Total Vulnerability Index (TVI), which characterizes the vulnerability of the three barangays in five classes, from very low to very high vulnerability.

1. INTRODUCTION

The impact of sea-level fluctuations as a potential climate change effect had been an emerging issue on coastal communities and systems. The use of merged satellite altimetry data for the various parameters of climate change has provided sufficient evidences for the rising sea level. Projections by the Intergovernmental Panel on Climate Change (IPCC) approximated that sea level is rising globally at about 15 to 95 centimeters by 2100 as a result of the ocean thermal expansion and the melting of ice caps. Geological and tide gauge data supply 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 and White, 2006).

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). The most widely used index used in risk and vulnerability assessments 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 emphasizes the relative vulnerability of the coast to physical changes due to future sea level rise (Dwarakish, et al., 2009). Moreover, the integration of socioeconomic variables with the CVI, developing a Socioeconomic Vulnerability Index (SVI) which is dependent on the locally relevant socioeconomic factors 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 indices have used low resolution digital elevation models (DEM) and are presented at the regional scale.

Satellite altimeters have been measuring sea level anomalies for almost two decades. These sea level anomalies are deviations from the mean sea level values and can be used to analyze the spatial variability and rates of sea level rise. Trends of sea level variations in the South China Sea were obtained using merged altimetry data from various satellite altimeters, which include TOPEX/POSEIDON, Jason and ERS-1/2 (Cheng & Qi, 2007). Sea level anomalies from

October 1992 to January 2006 were analyzed for depths up to 200 meters and additional tide gauges data were incorporated to determine near shore trends. Results show that the South China Sea has a rise rate of 11.33 mm/yr from 1993 to 2000 and significant sea level fall from 2001-2005. With information gathered from satellite altimeters, factors that influence sea level variations can be determined. Sea level rise or fall rates can also be derived and used to obtain, which can be incorporated with tide gauges data to provide good approximations of mean sea levels at regional scales over long periods of time.

The Philippine archipelago has an enormous combined 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). Local sea level studies in the Philippines are very limited. One of the first studies on the effects of future sea level rise was conducted in Manila Bay (Perez, Amadore, & Feir, 1999). Accelerated sea level rise scenarios and the assessment of physical changes and natural system responses were employed to derive the extent of inundation. Results show that for a very high sea level rise of 1 meter, coastal barangays from nineteen municipalities of Metro Manila, Bulacan and Cavite will be inundated, approximately about 5555 hectares. A more participatory approach was used to determine the socioeconomic vulnerability of coastal communities in Cavite City (Sales, 2009). Results of the study suggested an appropriate local framework for integrating adaptation strategies and actions for an integrated coastal management (ICM) planning that can respond to sea level variations. Appropriate policy and institutional reform, capacity building and improved knowledge management were recommended to direct the development of coastal communities towards an increasing resilience and adaptive capacity to present and future climate risks.

High resolution DEMs are the key to accurately determining the extent of the effects of sea level rise. A Digital Surface Model (DSM) with an accuracy ranging from 1 meter to 3 meters can be derived from high resolution satellite images like IKONOS and SPOT HRG/HRS, which employ the use of linear array CCD technology, through multiple primitive multi-image matching (Zhang & Gruen, 2006). DSM can be further reduced to Digital Terrain Models (DTM) or DEM, which present precise approximations of elevations. Using higher resolution DEMs of the coast can drastically improve the susceptibility of coastal communities to rapid sea level rise. The emergence of terrestrial laser scanners (TLS) can further improve these elevation models and provide a more detailed analysis of the coastal topography.

The availability of satellite altimetry data and high resolution satellite images, integrated with geographic information systems (GIS) have provided a faster and more efficient method of risk and vulnerability assessment of coastal communities to accelerated sea level rise, both in the regional and global scales. It integrates both physical and socioeconomic vulnerabilities that characterize the degree of risk. The use of higher resolution DEMs and locally relevant information will be incorporated in the research to provide a local scale of the vulnerability assessments.

2. STUDY AREA

Bolinao, Pangasinan (Figure 1) is a municipality located at the western part of the Lingayen Gulf and is bounded on the north and west by the South China Sea, on the east by the Caquiputan Channel and on the south by the municipality of Bani. It is situated along the latitude 96° 16' to 96° 26' and longitude 119° 45' to 119° 57' with an approximate area of 23,320 hectares.

Bolinao is one of the numerous communities in the Philippines which earn their primary income from fishing activities and fish-related businesses because of the diversity of its marine ecosystem, which host abundant ocean resources.

Barangays Luciente 1.0, Germinal and Concordia are the coastal communities located at the town proper (Figure 1) and were ranked as the 1^{st}, 4^{th} and 5^{th} most populous barangays in the municipality. A significant fraction of the population of these barangays live near the shore and are highly susceptible to the possible risks posed by future sea level rise.

Figure 1. The location of Bolinao, Pangasinan. The province is bounded on the west by the South China Sea (left). It is situated at the northwestern tip of Pangasinan (center). The WorldView-II image of the three barangays.

3. METHODOLOGY

The study is comprised of four major stages: (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.

3.1 Sea Level Rise Assessment

Sea level anomaly data from multiple satellite altimetry missions including 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). Corrections applied 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. The sea level variations recorded by these satellite altimeters are compared with existing tide stations maintained by the National Mapping and Resource Information Authority (NAMRIA).

3.2 Derivation of High Resolution Elevation Data

Using high-resolution satellite images like Quickbird and WorldView-2, a high resolution digital elevation model (DEM) is generated. A more detailed DSM is obtained through terrestrial laser scanning surveys using Leica ScanStation 2. Merging these elevation data will provide a more accurate topography of the coastal communities.

3.3 Socioeconomic Data Gathering and Analysis

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.

3.4 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. 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.

4. PRELIMINARY RESULTS AND DISCUSSIONS

4.1 Mean Sea Level Data from Existing Tide Stations

The San Fernando, La Union tide station is the nearest tide station to Bolinao, Pangasinan located at 16° 37' N, 120° 17' E. However, this tide station is not continuously in active operation for the past 60 years and was only to record nine years of annual mean sea level (Figure 2).

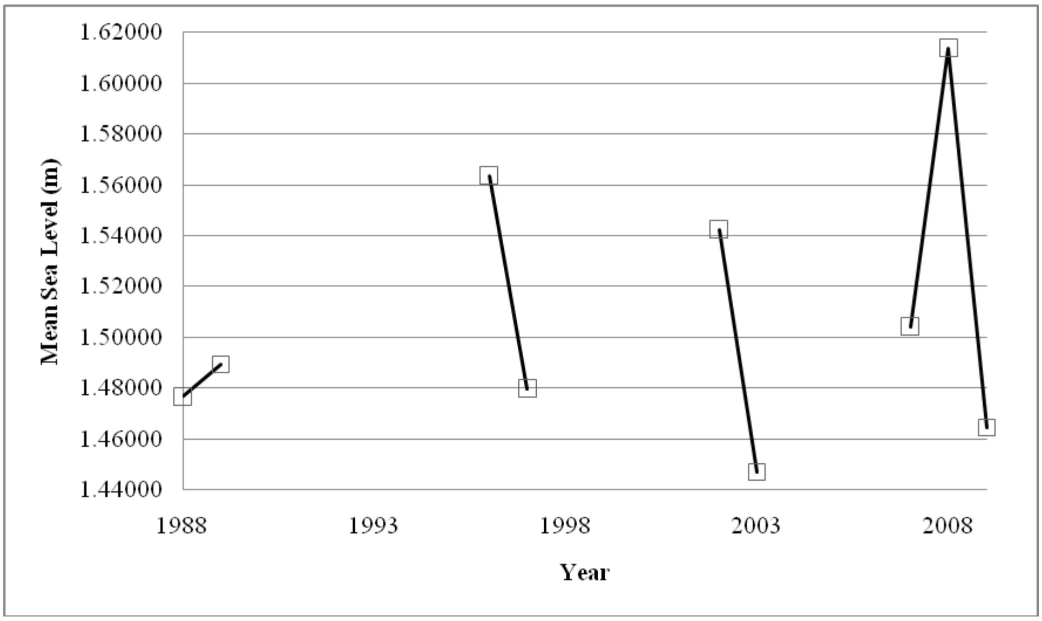

Figure 2. The annual mean sea level records of the San Fernando Tide Station.

The Manila South Harbor station located at 14° 34’60”N, 120° 58’E has been in operation for the past 64 years (Figure 3). This tide station will be used to calibrate the sea level data that will be derived from satellite altimetry missions.

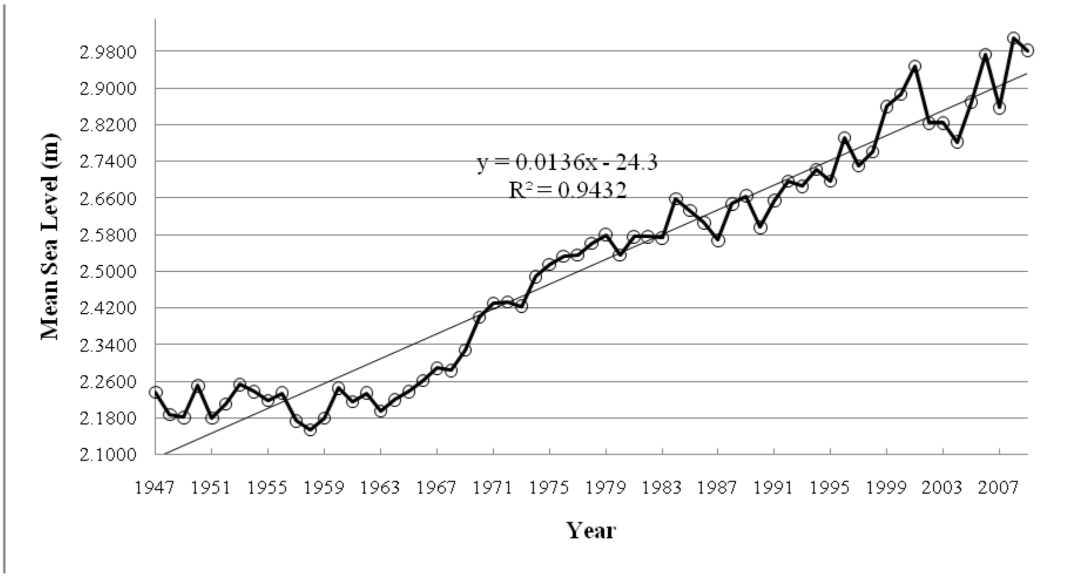

Figure 3. The annual mean sea level records of the Manila South Harbor Station.

The records from these tide stations are not sufficient enough to calibrate and validate the sea level data derived from satellite altimetry missions. Additional data from tide stations are required and must be situated in the proximity of the South China Sea.

4.2 Socioeconomic Data

The socioeconomic data gathered from the three barangays indicated that more than 20% of the recorded population live near the coasts (Figure 4). Most of these families rely on fishing and fish-related businesses.

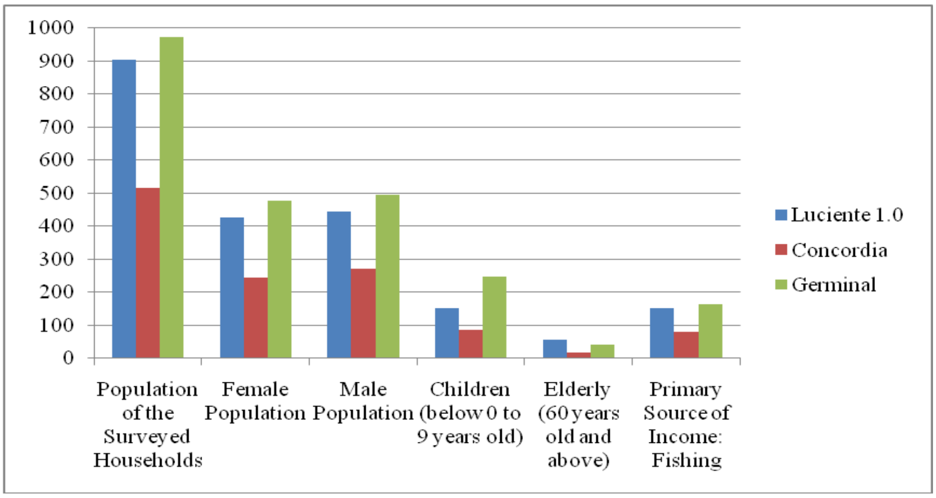

Figure 4. The statistics of the three barangays.

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. 3 Sea Level Variations from Satellite Altimetry

Merged satellite altimetry data provide an overview of the sea level variations for about a period of two decades (Figure 5). 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.

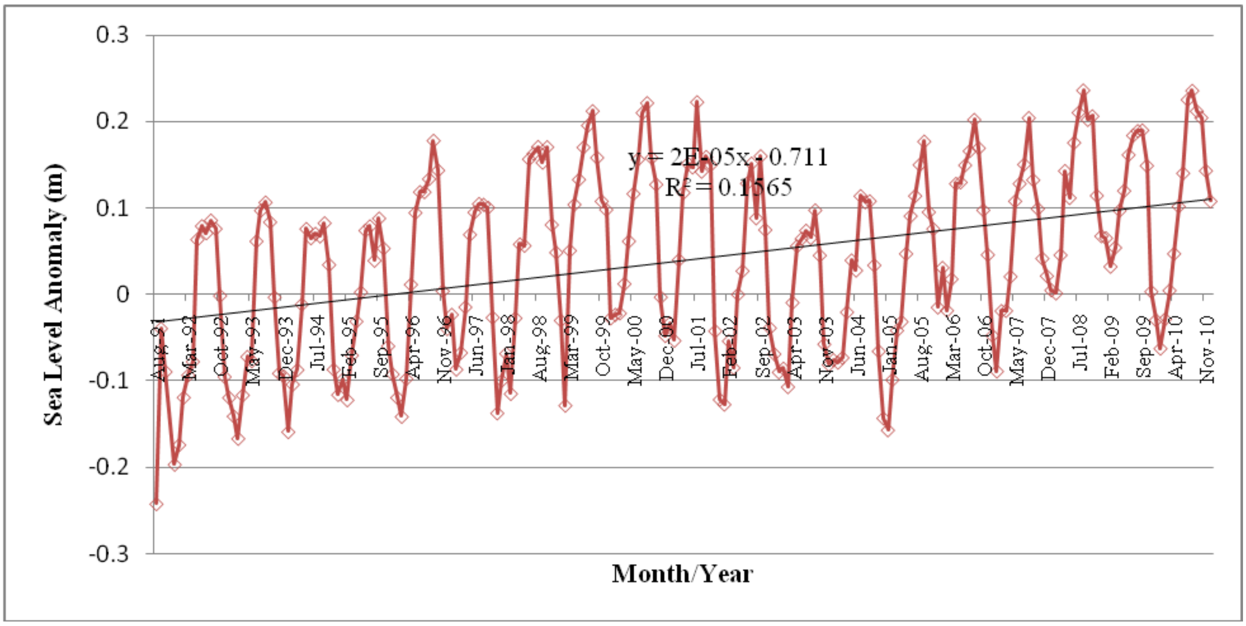

Figure 5. Monthly sea level anomaly averages obtained from merged altimetry missions from 1991 to 2010. The monthly records indicate a rising trends in sea level.

To further illustrate the sea level variations, sea level anomaly contour maps were generated at five year intervals from 1991 to 2010 (Figure 6).These maps indicate significant differences in the sea level anomaly trends and indicate a rise in sea level.

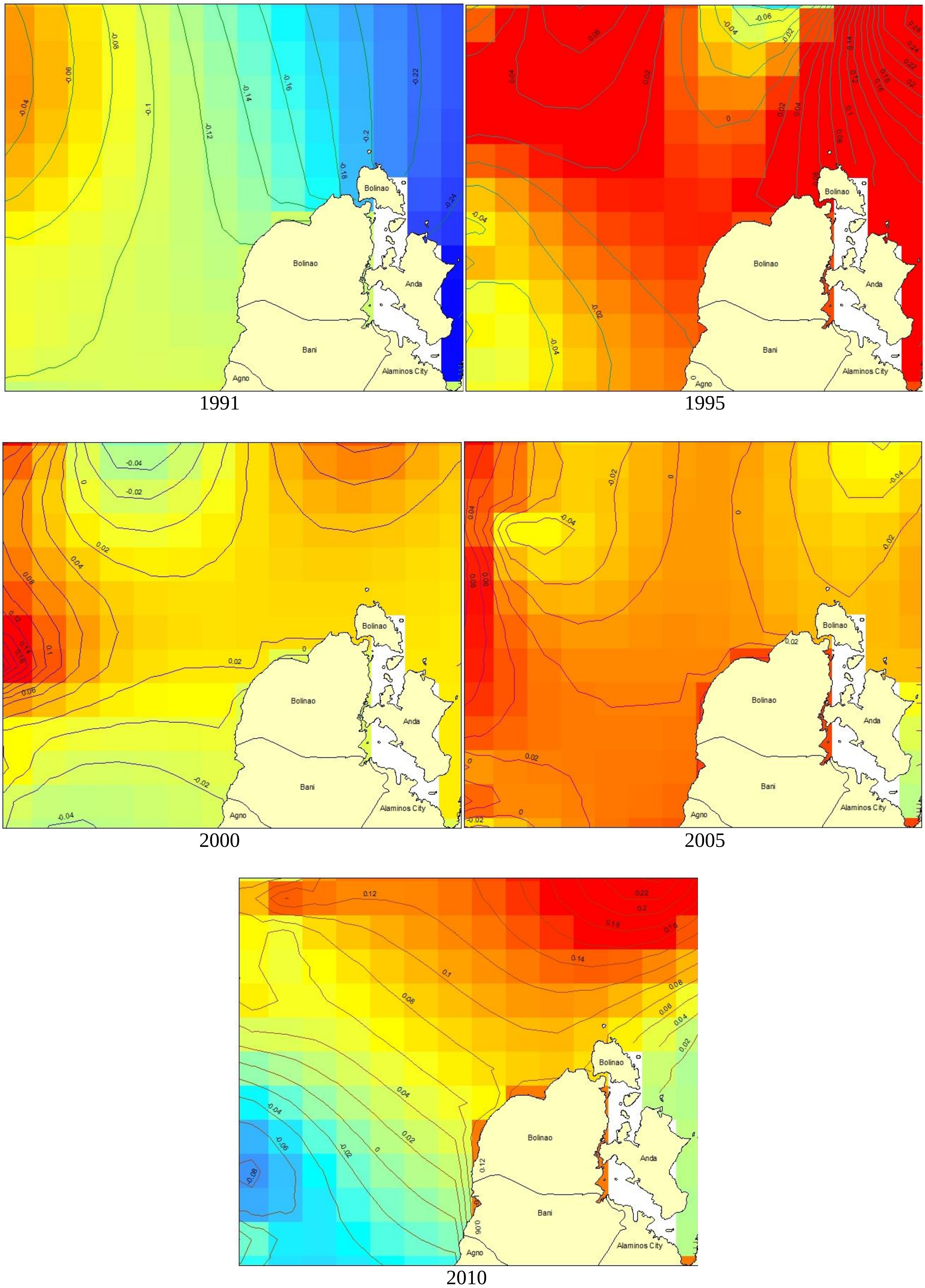

Figure 6. Sea level anomaly trends from 1991 to 2010 in four and five-year intervals.

5. Conclusions and Future Work

The surveys carried out in the study area have verified the potential risks of future sea level rise to 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 merged data obtained from several altimetry missions provide an effective scheme of analyzing sea level variations over a long period of time. The need for additional tide gauge records is necessary to further verify the accuracy of the data obtained from satellite altimeters.

Generating the high-resolution DEM that can illustrate possible flooding events due to sea level rise is currently in progress. The best weighting method is also being determined for the calculation of the CVI and TVI to derive the best approximation of the vulnerability of these communities.

References from Journals:

Capili, E. B., Ibay, A. C., & Villarin, J. T. (2005). Climate Change Impacts and Adaptation on Philippine Coasts. *Proceedings of the International Oceans 2005 Conference*, (pp. 1-8). Washington D. C.

Cheng, X., & Qi, Y. (2007). Trends of sea level variations in the South China Sea from merged altimetry data. *Global and Planetary Change* , 371-382.

Church, J. A., White, N. J., Aarup, T., Wilson, W. S., Woodworth, P. L., Domingues, C. M., et al. (2008). Understanding global sea levels: past, present and future. *Sustatinability Science* , 9-22.

Doukakis, E. (2005). Coastal Vulnerability and Risk Parameters. *European Water* , 3-7.

Dwarakish, G. S., Vinay, S. A., Natesan, U., Asano, T., Kakinuma, T., Venkataramana, K., et al. (2009). Coastal vulnerability assessment of the future sea level rise in Udupi coasta zone, of Karnataka state, west coast of India. *Ocean & Coastal Management* , 467-478.

Harvey, N., & Nicholls, R. (2008). Global sea-level rise and coastal vulnerability. *Sustainability Science* , 5-7.

Hinkel, J., & Klein, R. J. (2006). Integrating Knowledge for Assesing Coastal Vulnerability to Climate Change. In L. McFadden, R. Nicholls, & E. C. Penning-Roswell, *Managing Coastal Vulnerability: An Integrated Approach* (pp. 1-20). Amsterdam: Elsevier Science.

Perez, R. T., Amadore, L. T., & Feir, R. B. (1999). Climate change impacts and responses in the Philippine coastal sector. *Climate Research* , 97-107.

Rao, K. N., Subraelu, P., Rao, T. V., Malini, B. H., Ratheesh, R., Bhattacharya, S., et al. (2008). Sea-level rise and coastal vulnerability: an assessment of Andhra Pradesh coast, India through remote sensing and GIS. *Journal of Coastal Conservation* , 195-207.

Sales, R. F. (2009). Vulnerability and adaptation of coastal communities to climate variability and sea-level rise: Their implications for integrated coastal management in Cavite City, Philippines. *Ocean & Coastal Management* , 395-404.

Szlafsztein, C., & Sterr, H. (2007). A GIS-based vulnerability assessment of coastal natural hazards, state of Para, Brazil. *Journal of Coastal Conservation* , 53-66.

Zhang, L., & Gruen, A. (2006). Multi-image matching for DSM generation from IKONOS imagery. *Photogrammetry and Remote Sensing* , 195-211.