

# **NDVI Comparison for Pre and Post-tsunami Images Using Quickbird High Resolution Images in Chilka Lake, India**

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## **ABSTRACT**

This project analyses the 2004 tsunami effects on Chilka Lake in Orissa (India), measuring Normalized Difference Vegetation Index (NDVI) values, and conducting supervised and unsupervised classification using two QuickBird High Resolution Images. The ENVI tools used for these classifications were Maximum Likelihood for supervised classification, and IsoData and K-means for the unsupervised classification. Pre-tsunami and post-tsunami images were compared in order to assess any damage and differences in NDVI values. Chilka Lake, being recognized as one of the most important wetlands in the world, was not significantly affected by the 2004 tsunami that originated from a 9.0 earthquake offshore of Sumatra, Indonesia. This was probably due to high altitude sand dunes that acted as natural barriers by protecting the land from the tsunami and the continental platform that dissipated the wave energy. There were changes found in the NDVI, supervised and unsupervised images probably due to the land management more than a tsunami wave effect. There were minimum classification differences, in both supervised and unsupervised images, in some of the inland water body areas due to shrimp farms that presented a distinctive color.

**KEYWORDS:** Tsunami effects; NDVI; Natural barriers; ENVI; Aerial photographs; Quickbird; Chilka Lake

## INTRODUCTION

The December 26, 2004 tsunami was the result of a 9.0 earthquake with an epicenter near the northern tip of Sumatra in Indonesia. It impacted a large part of the coastal regions in and around the Indian Ocean and surrounding water bodies (Kouchi 2007). This tsunami not just affected countries surrounding the epicenter, but it traveled as far as Port Elizabeth in South Africa, 8000 km away from the epicenter where it also caused serious loss (Kume 2009). We speculated that Chilka Lake, and its rich biodiversity located in the eastern coast of India (Ghosh et al. 2006), was going to be heavily impacted being that it is situated in the state of Orissa and was closer to the earthquake epicenter than Africa.

Massive quantities of sea water inundated land 0.5–2.0 km inland from the coast of the Nagapattinam District, Tamil Nadu, India (Kume 2009). An important aspect of the Orissa tsunami event is that a very limited area was affected (Mishra 2014). In order to explain the apparent discrepancies, we suspected that there were natural barriers protecting this area. Another possible explanation is a dissipation of tsunami energy due to the continental platform. To attempt to clarify this unusual tsunami event, we used Remote Sensing (RS) techniques to see if we can detect change comparing pre and post-tsunami images on a few kilometers of the coast of Chilka Lake. RS has been a key tool for conservation of natural resources, ecosystems, and biodiversity by the monitoring of landscapes over time. Its techniques provide effective tools for analyzing the land use dynamics of the region as well as for mapping and management of natural resources (Adikanda

2013). The company DigitalGlobe donated high resolution satellite images of various areas of the coast of the Indian Ocean. This was part of an effort to promote research for tsunami hazard mitigation, due to the devastating 2004 tsunami event that reached the coast of many countries (University of Maryland 2014).

Several studies using remote sensing have been carried out in the most affected areas of India by the 2004 tsunami that describe its effects on soil, groundwater, and vegetation. For example, in a study done at the Nagapattinam District (southern India), the inland salinization problems caused by the sea water inundation from the tsunami were observed using before and after the tsunami images of the MODIS sensor and measuring its NDVI values. This study showed that vegetation damaged by the tsunami recovered to its pre-tsunami state after a year (Kume et al. 2009). Other studies indicate that offshore bathymetry is key for predicting tsunami coastal behavior. And that local coastal characteristics such as dunes, vegetation, and steep beaches have been observed to play a vital role in reducing tsunami effects (Patnaik et al. 2012).

Therefore, the objective of this study was to use QuickBird High Resolution Images was to evaluate and compare NDVI values for pre-tsunami images and post-tsunami images, and to perform an accurate supervised and unsupervised classification in order to assess tsunami effects.

## EXPERIMENTAL METHODS AND DESIGN

*Study area-* Chilka Lake, also referred as Chilika, is India's biggest lagoon. Its body of water ranges from 1,165 km<sup>2</sup> in the rainy season to 906 km<sup>2</sup> in the dry season. It is situated on the east coast of India, in the center of Odisha (Orissa) coast, it extends from Bhusandpur in Puri district

in the North to Rambha-Malud in Ganjan district in the South. In the lagoon, there is a combination of freshwater runoff from the drainage basin with saline water inflows from the ocean. Accordingly there is a wide range of fresh, brackish and saline water environments within this lagoon. The most influential factor determining the lagoons ecology is the salinity (Ghosh et al. 2006). Which is separated from the Bay of Bengal by a barrier spit attached at the southern end. The spit has curvatures of different magnitudes and landward of the spit, but adjacent to it, are a number of other sand ridges, some of which are parallel to the coast (Venkatarathnam 1970). The Lake takes in resident and migratory species, some endangered. These site was selected for the study because it is a touristic site that contributes to the economy of Orissa (Ghosh et al. 2006), and because the quality imagery that we stumbled upon does not usually have free access. DigitalGlobe and GeoEye-OrbImage donated images after the tsunami disaster to promote research in the area.

As indicated in a study done in 2012 at Chilka Lake, the greatest share of land use and land cover is agricultural land, which covers an area of 125730 ha, that is 26% of the total area. The aerial size of the dense forest is 61377 ha (13 %), whereas the rural settlement and urban settlement is 47078 ha (10%) & 11029 ha (2.29%) from the total area of the Lagoon. Hence, 18% of the total area of the catchment is covered by Chilka Lake (Ojha et al. 2013). The Lagoon system harbors at least 185 species of plants in the aquatic and terrestrial island of known medicinal properties. Also, of the total floral diversity in the lagoon area, there are species used as local vegetables, fodder, thatching, fish food, and bird feeding and nesting. There are also shrimp and prawn farms in the lake (Ghosh et al. 2006).

*Satellite sensor-* QuickBird satellite collects image data to 0.65m pixel resolution degree of detail using a state-of-the-art BGIS 2000 sensor. This satellite was turned off on January 27, 2015, after

completing its 13-year mission in orbit. It was an excellent environmental data collector, its data is now useful for analyses of changes in land usage, agricultural and forest climates. QuickBird's imaging capabilities are excellent for this type of environmental studies. The Satellite Sensor, had an orbit altitude of 450 Km / 482 Km, with a speed of 7.1 Km/sec, an orbit time of 93.5 minutes, and a revisiting time of 1-3.5 days, depending on latitude (30° off-nadir). We managed to acquire a set of images of the same area 18 days after the first images were taken. Swath Width (Nadir) 16.8 Km/ 18 Km, metric accuracy of 23 meter horizontal (CE90), and a digitization of 11 bits. QuickBird has a Pansharpening resolution of 65 cm (nadir) up to 73 cm (20° off-nadir), and an Mass Spectrometry resolution of 2.62 m (nadir) to 2.90 m (20° off-nadir). The images are perfect for NDVI analysis because of the image bands it has available; Pan, blue, green, red, Near IR (Satellite Imaging Corporation 2015). The red and Near IR bands are considered to give the good indicators of land cover characteristics and, in fact, the NDVI values are calculated using these two bands. This is a fundamental analysis for tsunami damage detection in vegetated areas (Kouchi 2007).

*Processing of High Resolution Images-* The images acquired were already corrected for the atmosphere interaction and they were geo-referenced. We had pre-tsunami images from December 11, 2004, and post-tsunami images from December 29, 2004. Using ENVI 5.3.1 we gathered a total of 12 pre and 16 post-tsunami images to see which set of images overlapped. A Seamless Mosaic was done with the set of images that overlapped in some regions and then a spatial subset in the coastal area where both mosaicked images would completely overlap. The subset (Fig. 1) image area is around 9.3km<sup>2</sup>. Pan-sharpening was made to increase the spatial resolution from 1.5m to 0.71m of each pre and post-tsunami subset. It is possible to identify the areas where the

land cover class has changed to tsunami impact and inundation areas by demonstrating the applicability of the vegetation index, and analyzing its values. From the reflectance of the red (RED) and near-infrared (NIR) bands, the Normalized Difference Vegetation Index (NDVI) was computed using the following Equation (Kouchi 2007);  $NDVI = (NIR - RED) / (NIR + RED)$ . A mask was created and set on both NDVI images to cover the water bodies. To determine which unsupervised algorithms was the best for this study we ran the classification for 7 classes and compared the following; K-mean and Iso-data. Last, prepared a ROI file with 5 classes of interest (Sand, water, crops, shrimp farms, and shrubs) and saved it to create a Supervised Classification using the Maximum-likelihood method.



Figure 1. Spatial subset of study area at Chilka Lake (12/11/2004)

## RESULTS AND DISCUSSION

After implementing the according pre-processing methods and applying the presented methodology, the following images where acquired. See Figure 2 for NDVI images. As seen in

these figures the expected differences were not met. NDVI values were expected to be significantly lower on the post-tsunami image as shown in Kouchi et al. 2007.

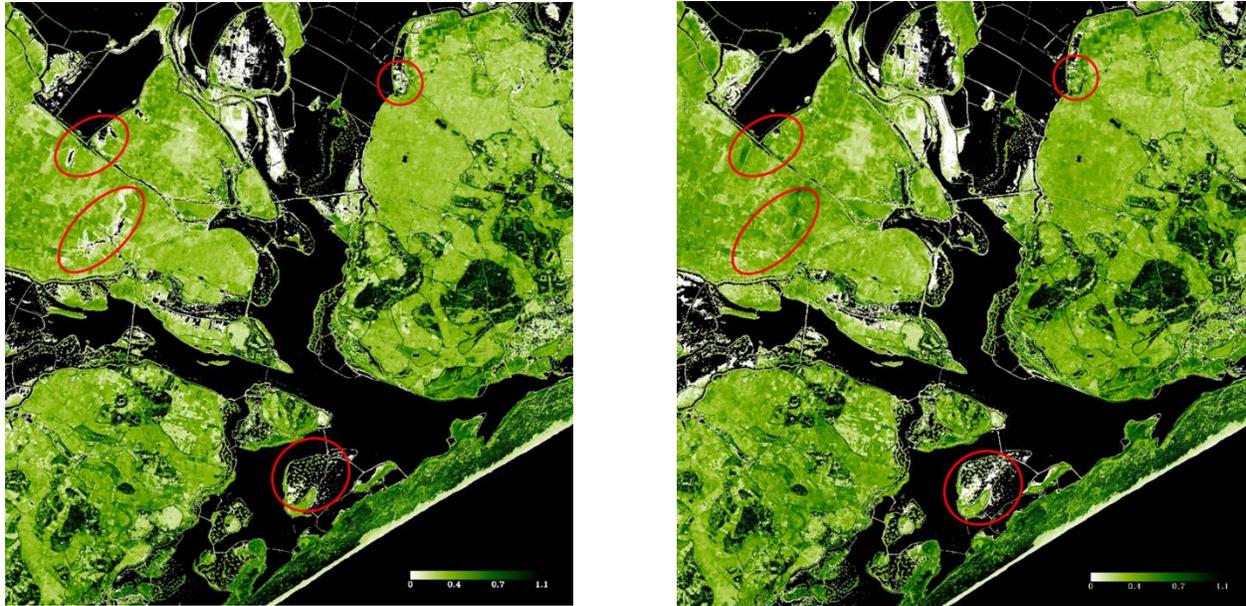


Figure 2. NDVI image for Pre-tsunami 12/11/04 (left). NDVI image for Post-tsunami 12/29/04 (right).

As seen in the images, there are no significant differences between them. The circled areas are just some areas where it is visually noticeable that there are some changes. These differences were probably due to agriculture practice in the region and not a tsunami wave impact. A statistical analysis was performed for the NDVI values and the results are shown in Figure 3.

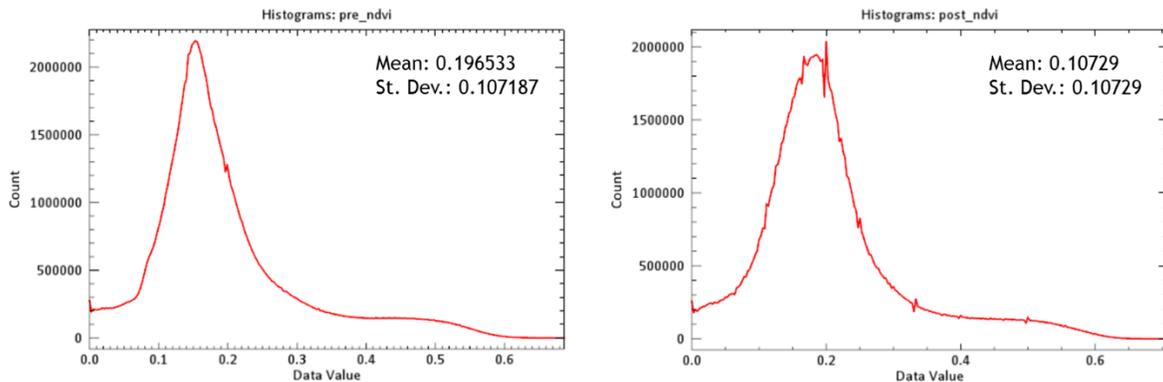


Figure 3. Histogram showing the statistical analysis for NDVI values.

For a quantitative description, Figure 3 shows the histogram of NDVI values for the pre-tsunami image and post-tsunami image. The mean value for NDVI in the pre-tsunami image is 0.20 while the post tsunami image is 0.21. These values indicate that the studied area did not have many densely vegetated areas. This difference in mean values is not the expected when a tsunami wave affects a coastal zone. The crops and wetlands show low NDVI values probably due to moisture in the soil that absorbs most of the near infrared band; therefore lowering the NDVI values. These results indicate that the tsunami waves did not impact significantly the vegetation of this region. In order to see if there were further differences, two unsupervised classification methods were applied: K-mean and Iso-data. The resulting images are presented in Figure 4 and Figure 5.

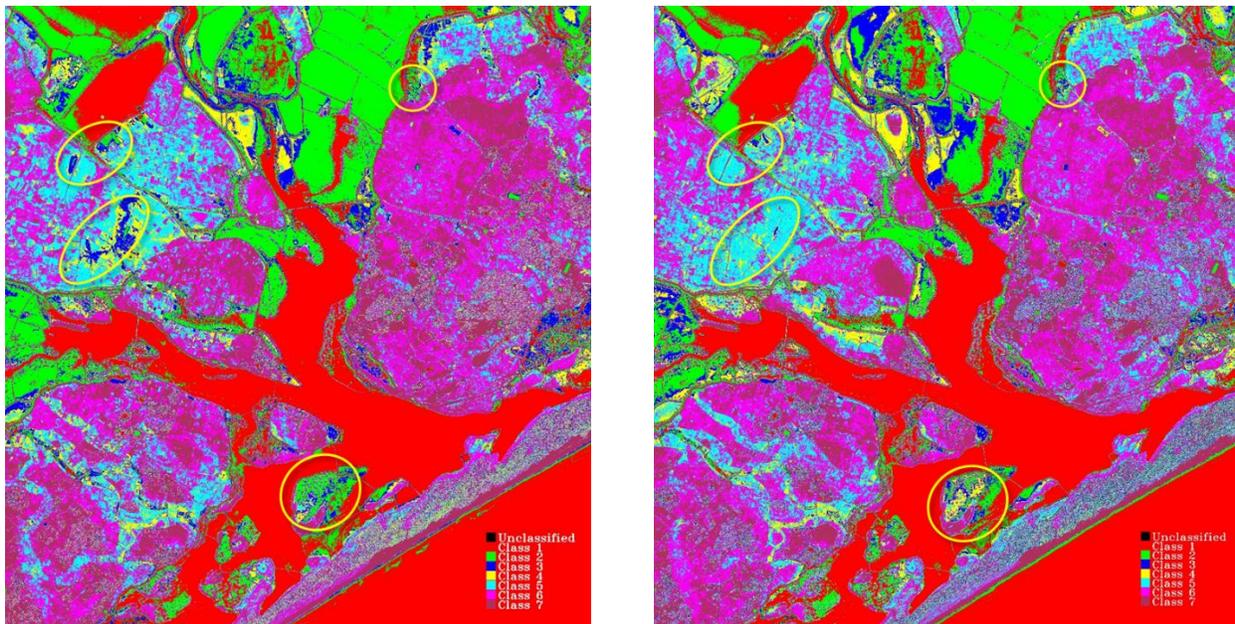


Figure 4. K-mean unsupervised classification images for pre-tsunami (left) and post-tsunami (right).

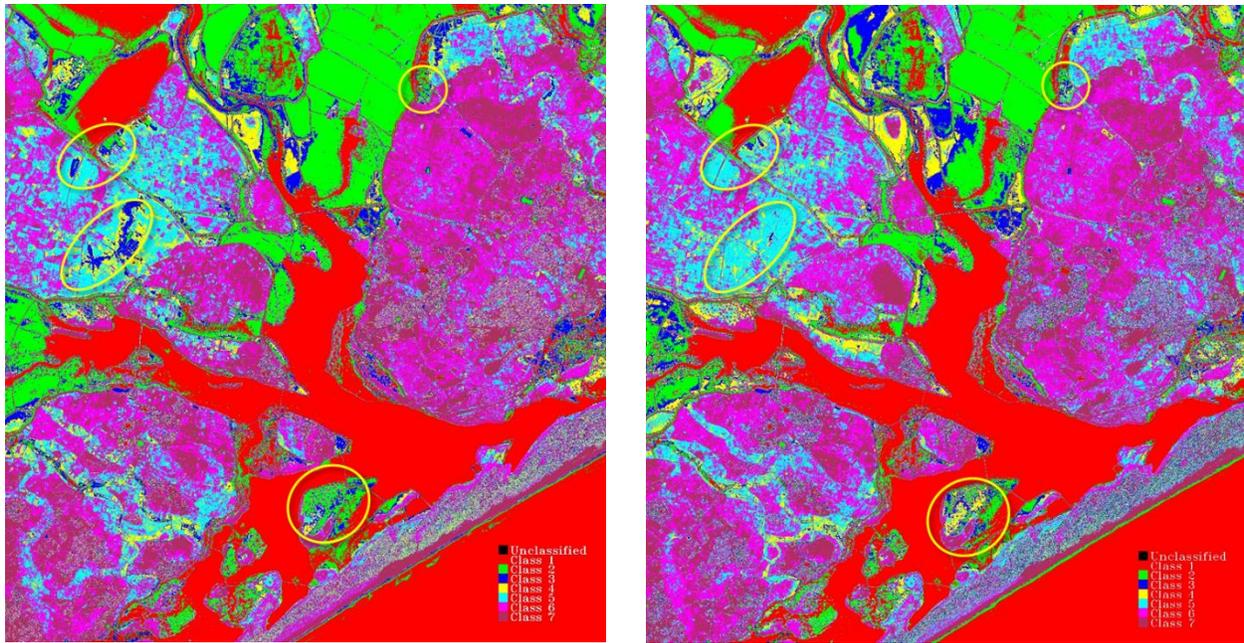


Figure 5. Iso-data unsupervised classification images for pre-tsunami (left) and post-tsunami (right).

Both unsupervised classification methods did not show significant differences in the class distribution. Both methods showed differences in the same areas as the other images, now circled in yellow, but these differences are not attributed to tsunami waves as shown in Kouchi et al. 2007. For further analysis, a supervised classification was conducted in order to assess the different types of environments that could be affected by a tsunami wave in the coast. The supervised classification method used was Maximum-Likelihood from the ENVI toolbox and the results are presented in Figure 6.

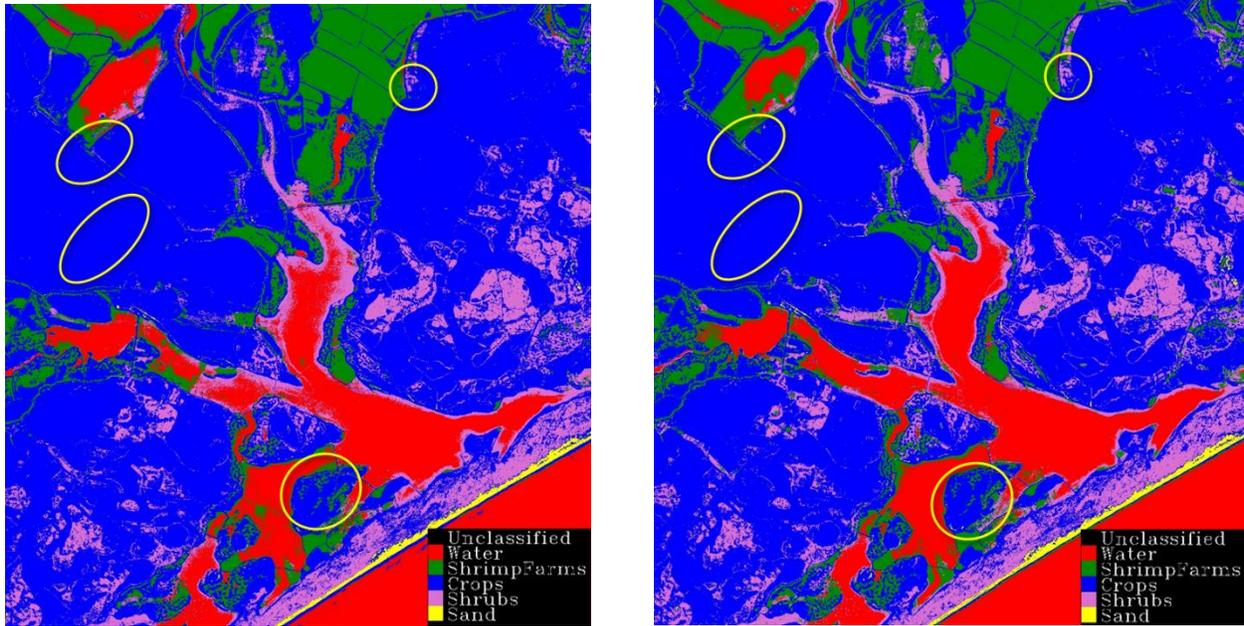


Figure 6 Maximum likelihood supervised classification method for pre-tsunami image (left) and post-tsunami image (right).

As shown in Figure 6, there are no significant differences in the post-tsunami image. The yellow circles once again represent the areas where the previous images showed changed, but there is still no sign of a tsunami impact in the resulting image. If there were a high wave tsunami in the coast, the sand class should be affected, but no significant differences were shown in the sand class; in the pre-tsunami image 0.77% of the image pixels are classified as sand, while 0.67% of the total image pixels were classified as sand in the post-tsunami image.

Looking at our image results, we confirmed that Chilka Lake was not affected by the tsunami, when catastrophe happened at other areas of India like in Tamil Nadu (Kume 2009). A simulation study of the 2004 tsunami that originated from the Sumatra earthquake confirmed this for the Odisha and West Bengal coasts. The study mentioned that inundation along the coast varied depending on the

coastal geomorphology; beach ridges and sand dunes restrict the inundation process while swales, creeks, rivers and inlets permit free flow of water inland. Most of the geomorphology of Chilka Lake's coast is distinguished by elevated beaches and sand dunes that act as a buffer and restrict the inundation within the beach limit, therefore the coast is relatively safe and less vulnerable from a tsunami originating from the Bay of Bengal region like the 2004 tsunami. The study also pointed out to the fact that the propagation of a tsunami wave from deep water to coast largely depends on local nearshore bathymetry and coastal morphology (Mishra 2014). Studies have shown that deep-water waves as they approach shallow water dissipate energy (Panigrahi 2010). The continental shelf of Orissa can be conveniently considered under three depth ranges; 0-50 m with an area of 19,195 km<sup>2</sup>, 50-100 m within 7410 km<sup>2</sup> and the third depth 100-200 m is 5674 km<sup>2</sup> (Ali 1996). A study about the bathymetry in east and southeast India shows a steeper shelf in the southeast area, the tsunami run-up heights were found to be higher the farther you move from the east side towards the south. This is because the tsunami wave builds up very fast in shallow water and since the continental shelf is narrow in the south, less attenuation of energy is happening and therefore there will be higher waves. In the eastern zone, where Chilka Lake is located, the shelf is less steep. Therefore, the tsunami loses energy during its propagation and becomes slower. In this zone lower run-up heights were recorded. From this it is evident that continental shelf also plays a crucial role in tsunami propagation (Patnaik et al. 2012). This also explains why in the Tamil Nadu in the Nagapattinam District, which is located in southern India, was so gravely affected by the tsunami (Kume 2009).

If it wasn't for the continental shelf that dissipated the energy from the tsunami wave, there would have been a high probability of the wave harming the ecosystem and biodiversity in the area. Especially since the tsunami occurred in December, when many species are migrating to the Lagoon (Ghosh et al. 2006).

## CONCLUSION

According our image results, there is no significant evidence of a tsunami-affected area in the Chilka Lake. The small changes were probably due to the land management. The reality of Chilka Lake not being affected by the tsunami was confirmed by the literature found about its natural barriers, such as sand dunes in the coastline with heights of 9-15 m (Venkatarathnem 1970). The extensive shallow continental shelf is also an indication of wave energy dissipation and, consequently, there was no tsunami impact on the coastline (Satake 1988). The coastal areas, farthest away from the extensive continental shelf around Chilka Lake, on the south-west side of India had more impact of the tsunami wave. This is because as farther south the area is from Chilka Lake, the shelf becomes more narrow and shallow which causes waves to rise. The width of the continental shelf also played a crucial role in causing damage to the coast.

For ongoing efforts or future studies; it is always relevant to acquire, if possible, field data in order to assess the effects and then quantify the resulting damage of a tsunami. Management plans can be designed using the information provided by this study as baseline, as for future land use planning, building tsunami control/resistant habitats, and hazard management along the coastal areas. Design an outreach program to create emergency plans and awareness of the vulnerability status of the northeastern India coast to tsunami.

## ACKNOWLEDGEMENTS

We appreciate the donation of imagery by DigitalGlobe for this tsunami assessment effort. And sincerely thank Professor Fernando Gilbes, of the Department of Geology in the University of

Puerto Rico - Mayaguez campus, for his keen interest and encouragement in conducting this research for the Remote Sensing course.

## REFERENCES

- Ali, S. M. 1996. Marine Fisheries Economics and Development in India (A case study of Orissa). M D Publications Pvt Ltd.
- Ghosh, A.K., and A.K. Pattnaik. 2006. Chilika Lagoon: Experience and Lessons Learned Brief. [http://www.worldlakes.org/uploads/08\\_chilika\\_lagoon\\_27february2006.pdf](http://www.worldlakes.org/uploads/08_chilika_lagoon_27february2006.pdf).
- Kouchi, K., and F. Yamazaki. 2007. Characteristics of Tsunami-Affected Areas in Moderate-Resolution Satellite Images: IEEE Trans. Geosci. Remote Sensing IEEE Transactions on Geoscience and Remote Sensing, 45, 1650–1657.
- Kume, T., C. Umetsu, and K. Palanisami. 2009. Impact of the December 2004 tsunami on soil, groundwater and vegetation in the Nagapattinam district, India. Journal of Environmental Management. Vol. 90. Issue 10. P. 3147-3154.
- Mishra P., T. Usha, and M. V. Ramanamurthy. 2014. Evaluation of tsunami vulnerability along northeast coast of India. Continental Shelf Research. Vol. 79. P. 16-22.
- Murthy, K. S., A.S. Subrahmanyam, and V. Subrahmanyam. 2012. Tectonics of the Eastern Continental Margin of India. New Delhi: The Energy and Resources Institute (TERI). P. 44-51.
- Ojha, A., J. Rout, R.N. Samal, G. Rajesh, A.K. Pattnaik, and P. Daspatnaik. 2010. Evaluation of landuse/ landcover dynamics of chilika catchment. International Journal of Geomatics and Geosciences. Vol. 4.

- Panigrahi, J.K., V. S. Kumar, and J. K. Tripathy. 2010. Littoral drift by alongshore flow at Visakhapatnam – East Coast of India. *Journal of Hydro-environment Research*. V. 4. Issue 4. P. 317–327
- Patnaik, K.V.K.R.K., S.V.V Arun Kumar, Ch. V. Ramu, and K.V.S.R Prasad. 2012. Observational analysis on the run-up height and inundation along the Andhra coast during December 26, 2004 Indian Ocean tsunami. *Journal of Asian Earth Sciences*. V. 45. P. 239–246.
- Satake, K. 1988. Effects of bathymetry on tsunami propagation: application of ray tracing to tsunamis. *Pure and Applied Geophysics*. 126(1): 27-36.
- Satellite Imaging Corporation. 2015. QuickBird Satellite Sensor. <http://www.satimagingcorp.com/satellite-sensors/quickbird/>
- S.I.C., 2015. Satellite Imaging Corporation: QuickBird Satellite Imagery and Satellite Sensor Specifications. <http://www.satimagingcorp.com/satellite-sensors/quickbird/>.
- University of Maryland. 2014. Tsunami + Remote Sensing + Protected Areas. Global Land Cover Facility. <http://glcf.umd.edu/research/portal/tsunami/>.
- Venkatarathnam, K. 1970. Formation of the Barrier Spit and other sand ridges near Chilka Lake on the east coast of India. *Marine Geology*. v. 9, Issue 2, September 1970, p. 101-116.