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Coastline changes monitoring using satellite images of Makassar Coastal Areas

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Abstract

Coastal areas have been the target of rapid urban development in most large cities in Indonesia. Makassar City, the capital city of the South Sulawesi Province, is undeniably a fast growing city both economically and spatially. Especially the western coast of this city is rapidly growing in the form of coastal reclamation to accommodate the extension of settlement. This situation will continue in association with the social needs pursuing development to have better living conditions. As the number of population increases, industries have been triggered to provide new open areas for business and construction, and this situation inevitably demands spaces. Unfortunately the purposes of spatial planning of the city have not always been followed by the actual situations of spatial development. The coastline has changed drastically, with concentrated changes being observed along the coastline of Makassar beach such as at Tanjung Bayam and Losari Beach. In this study, we use Landsat satellite images acquired from 1990 to 2010 and Ikonos high-resolution, time-series images to monitor the coastline changes of the city. The interpretation is validated with the ground observations in survey campaigns conducted in some of the target areas. The temporal changes seen in the satellite time series are evaluated using newly developed software appropriate for raster images. The result of the present study strongly suggests that the human activity and coastal physical aspects are influencing the geomorphological changes in this city especially along the coastline of the city. This study is expected to contribute in the future city planning of Makassar when considering which areas to be developed for what purposes with better prioritization.

Keywords

Coastline changes; Landsat; Ikonos; time series changes

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1. Introduction

Urban centers have historically been connected to coastal or riverside areas. This is very natural because people tend to dwell where they find easy access to living supportive resources. Many big cities in the world along with their big ports have developed and grown with the increase of their population and settlement. The impact of modernization often appears as urbanization. It is needed to study how one city grows by accommodating the impact of civilization and to examine if the growth is safely sustainable for the residents therein. The city will expand and change along with its coastal areas which are usually recognized as a line. For the purpose of creating a better condition in the future, monitoring and recording the spatial changes along this coastal line is important for understanding what is existing now and also what has been existing in the past. According to Pardo-Pascual et.al (2012), coastline can change for two distinct reasons; 1) short-term variations of sea level that depend on astronomical and meteorological factors and 2) alterations in the shape and volume of sediments along the coastline. These latter changes in morphology are much less predictable because they are a response of the shore system to the ocean wave conditions. Such morphology changes can also be caused by the accumulation or erosion for a longer term.

One of the most effective ways to monitor the changes is by applying remote sensing media and techniques. Aerial photography has been used in the past as a primary data source. The most useful data extracted from aerial photography are the location of the waterline at the time of acquisition of the photograph. Over the conventional aerial photography, multispectral satellite imagery offers several advantages: a large number of data records, the availability of repeated images of a single place at different times, and the fact that the whole globe can be covered. As a result, multispectral satellite imagery is potentially more useful for recognizing evolutionary trends in the medium- and long-term. The Landsat images acquired by the TM and ETM+ sensors on the Landsat 5 and 7 series are the largest useable database of medium resolution images for studying the dynamics of coastal areas. Since 2008 the United States Geological Survey (USGS) has freely provided all archived Landsat images, along with newly acquired Landsat 7 ETM+ SLC-off and Landsat 5 TM images with less than 40% cloud cover, thereby enabling free access to multiple images of the same area. Currently Landsat 8, with specifications better than Landsat 7, is also available to be downloaded. Other than optical remote sensing, images acquired from the Synthetic Aperture Radar (SAR) system is capable of mapping the coastline changes and for the purpose of monitoring, a Differential Interferometry of SAR technique can be applied. The SAR sensor onboard JERS-1 satellite provides the ability to map the earth surface topography with the technique called Differential Interferometry SAR (DInSAR). The SAR records simultaneously the intensity and phase of the signal reflected from the surface. This technique has been used to measure the dimension of land subsidence phenomena in large cities of Indonesia such as Jakarta (Abidin et al., 2013; Bayuaji et al., 2010), Semarang, and Bandung (Sri Sumantyo et al, 2012).

The main objective of this study is to monitor the changes of coastline along the coastal areas of Makassar city using the time series changes of Landsat TM and ETM images validated with ground based sampling of coastal sediment and ground survey. Also, some of the JERS-1 images are exploited for the purpose of DInSAR analysis of the region of interest.

2. Study Area

The city of Makassar, the fourth largest city in Indonesia, is considered to be the gateway of Indonesia from the eastern part. Situated at the southwest part of Sulawesi Island, Makassar city covers an area of 175.77 km^2 divided into 14 sub districts. The city lies on the geographic coordinate of 119°18'27.97"-119°32'31.03" E Longitude and 5°00'30,18"

-5°14'6,49" S Latitude (Figure 1A). The landform is relatively flat, classified as alluvial plain with topography levels from 0- 21 m above sea level (Figure 1B). Geologically, the city is covered by four types of formation, Camba Volcanic Formation, Salo Kalumpang Volcanic formation (which mainly consists of fine sediment clastic of volcanic eruptive rocks but mostly eroded), a small area of Limestone Tonasa Formation and alluvium formation deposit as recent weathered material. In general, we can find three types of rock units, basalt, tuff and breccia derived from volcanic origins as well as sediment deposits like fine to coarse sand.

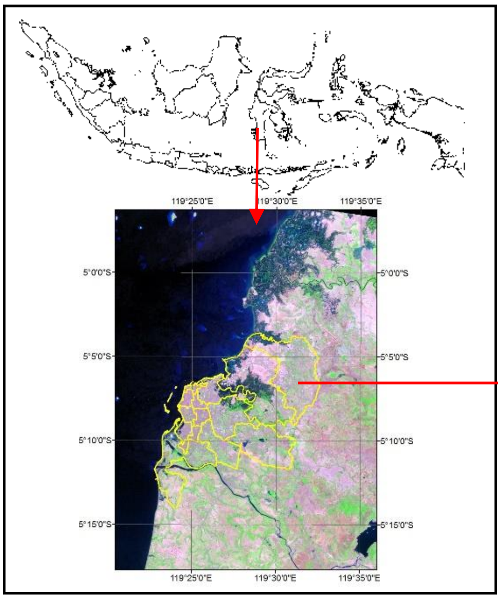

Figure 1A. Study Area

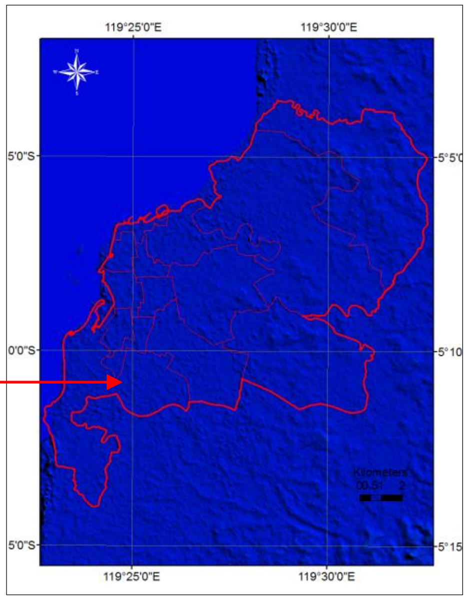

Figure 1B. The DEM of Makassar Area

The population of the city was 0.94 million in 1990, which increased to 1.65 million in 2012 [BPS, 2013], causing the increased use of both land surface and ground water. The rapid urbanization has made Makassar a center for economic development in eastern part of Indonesia. On the basis of the statistics of Makassar City, population has been increasing due to the development and urbanization. Hence, the situation continues in which people long for development to have better lives. The population increase triggers industries to develop new areas for business and construction. Since the governmental control is limited in the rural area surrounding the city, the agricultural, shrub, and even swamp spaces are developed, which in the future could generate land subsidence due to the extraction of water through wells. This mechanism has been suspected as the major cause of the subsidence phenomena that are often experienced in urban areas. Especially the reclaimed areas are considered to be vulnerable. In this context, the purpose of this study is to examine the temporal changes in Makassar coastal areas by means of satellite- and ground-based observations.

3. Data and Methodology

To accumulate the time series focusing on the coastline, we downloaded the whole image series available in the USGS database with path number 114 and row number 64 for this area. Both Landsat series of 5 and 7 have a spatial resolution of 30 m for the visible bands, except for the panchromatic band of Landsat 7, which has a pixel resolution of 15 m. The number of bands has increased to 11 bands for the Operational Land Imager (OLI) sensor onboard Landsat 8 with the addition of 3 infrared bands. The full list of the acquisition date can be seen in Table 1. The subsidence analysis and shoreline change detection are supported with Landsat images acquired in 1990, 1994, 1999 and 2013. Field campaigns were conducted in September 2009, January 2011 and March 2013 with handheld global positioning system (GPS) instruments. We also used high-resolution IKONOS images acquired in 2009 and QuickBird images acquired on May 6, 2007 for the detailed examination of ground corrections. Time series on specific changes on the beach profile are extracted from the Google Earth, on the basis of images ranging from 2000-2014 as shown in Table 1.

We also utilized 8 scenes of JERS-1 SAR images of level 0 that covers a swath area of 75 km^2. These images were obtained from 1993 to 1998 in the descending mode with 35.5 degree of incidence angle, but the area coverage available for the subsidence study is only 175.77 km^2. The DInSAR processing uses two pass interferometry to create an interferogram from two intensity (single-look, complex; SLC) images. Subsequently, the differential interferogram is flattened and unwrapped to obtain the deformation map of the subsidence area, while evaluating the depth of subsidence from the interferogram. As shown in Figure 3, the DInSAR image pair of 1995/1996 has indicated consistent pattern of subsidence in the subset of the image (Alimuddin et al; 2013).

We tried to apply object extraction method by overlaying the images. Many semi-automatic or automatic segmentation techniques were applied to extract the shoreline from variety of remote sensing data but there is no single method which can be considered well suited for all images (Chalabi et al, 2010). In this study, the methodology proposed for the extraction of the shoreline is based on segmentation technique. The shoreline changes are observed from the time series of the optical satellite images using segmentation delineation. This can be seen later (Figure 4) where we can compare the time series images of 1990, 2002 and 2013 showing the coastline changes.

Table 1. Data Type and Acquisition Date

Type of data	Date	Type of data	Date	Type of data	Date
Landsat 5 TM	19901216 19940829 19940202 19950606 19951212 20030707 20030721 20030808 20040707 20040925 20060919 20071004 20080819 20080830 20090502 20090721 20090801 20091025 20100214 20100724	**Landsat 7 ETM**	19990920 20000720 20001109 20010520 20010707 20020726 20020912 20020928 20030526 20040901 20070521 20100310 20100411 20110703	**IKONOS** (Pan-Sharpened Multispectral)	20001014 20010812 20040701 20050827 20060718 20070424 20090430 20100713 20121124 20131019 20140810
		Landsat 8 OLI	20130202 20140601 20140716		

Table 2. JERS-1 SAR Data acquisition and the pairs

Pair (RSP 78/309)	Week Differ	Base (m)	Bp (m)	Bh (m)
19930318/19941011	82	1250.27	1044.60	687.01
19941011/19950928	50	4648.04	3321.52	-3251.43
19950928/19960914	**50**	**1052.95**	**871.98**	**590.20**
19960914/19970422	26	1646.18	1277.33	1038.42
19970422/19970901	37	1708.45	1126.50	-1284.45
19970901/19980111	19	3376.06	2357.11	2416.99
19980111/19980819	30	1338.97	1178.81	-635.01

In Table 2 we can see the date acquisition, the number of week difference and the baseline information that is essential in acquiring a better coherence image. The closer the baseline the coherence image should be stronger. Other than the baseline, the atmospheric condition can also influence the differential image processed for the DInSAR analysis.

4. Results and Discussion

On the basis of the visual observation of Landsat imagery, urban development can also be seen from historical changes of the land cover. Landsat TM and ETM images acquired in August, 1994 and September 1999 were used to create landuse map of Makassar in 1994 and 1999, respectively. These optical images are compared with the intensity images of JERS-1 SAR images acquired at the similar time frame in Figure 2.

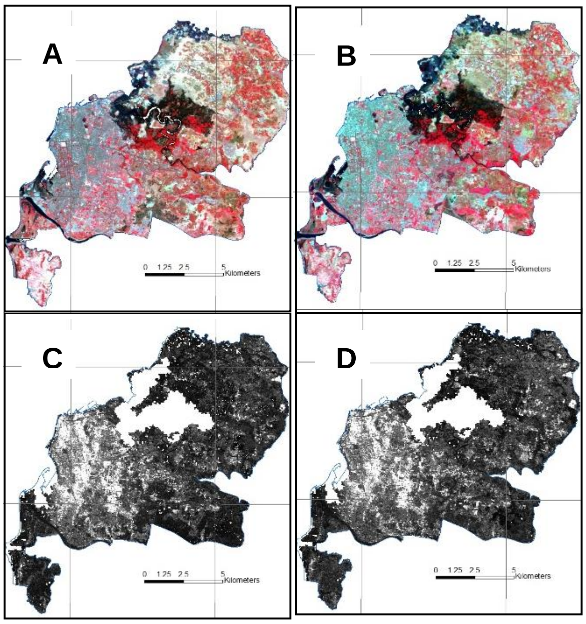

Figure 2. Satellite Images of A. Landsat TM_False Colour Composite (FCC) with band combination (BC) of 432 acquired on August 29, 1994. B. Landsat ETM FCC, with BC 432 acquired on September 20, 1999. C. Intensity Image of JERS-1 data acquired on October 11, 1994 and D. JERS-1 intensity image acquired on August 19, 1998.

The process of development can obviously be seen from the conversion of rice paddies, dry field and homogenous forest into business, services, and industrial area in the northern part of the city. The city expansion can also be seen from of settlement landuse change that brings more urban concentration to the areas in both northern and southwest parts near the coastal line. The new high rise apartments, hotels and public facilities were constructed in these particular locations of the city. Apparently the less compacted soil of coastal land is greatly affected by the weight of warehouses and factories built along the coastal highway.

As mentioned earlier, we processed eight datasets of JERS-1 SAR to create seven pairs to DInSAR images. Due to satellite orbital errors and influence of atmospheric conditions during the acquisition and considering the baseline difference of the two image used as master and slave images, three of the pairs have shown bad coherence hence cannot be further analyzed. In Figure 3 we can observe color coding patterns on the four images in some areas show some consistencies while other areas display bands of interferometry noises. We have chosen the pair image of 1995/1996 to be analyzed in detail, as shown in Figure 3: the coherence image is shown in 3.A, a subset image in 3.B and the deformation image in 3.C.

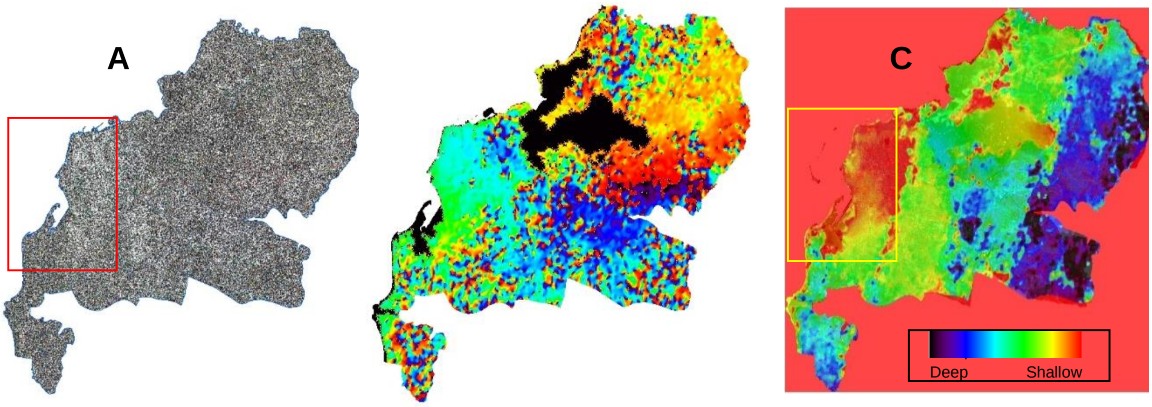

Figure 3. DInSAR Processing images of Makassar City. A. Coherence image of 1995/1996. B. DInSAR Image pair of 1995/1996 images C. The deformation image after the unwrapping process.

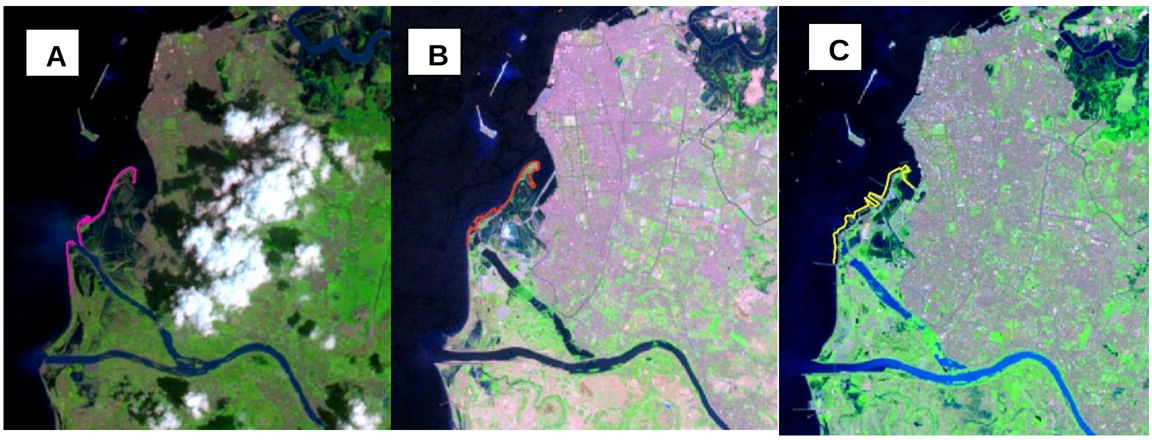

Figure 4. Satellite Images of A. Landsat TM_False Colour Composite (FCC)_Band combination of 743 acquired 19940829. B. Landsat ETM_FCC_743 acquired on 19990920. C. Landsat ETM FCC of 853 acquired on 20131019. Coloured line on the image indicates coastline delineation.

Based on the satellite time series analysis (Figure. 4), it is obviously seen how the changes occurred along the coastal areas. Most changes occurred in areas with the sediment supply and reclaimed areas, shown with the colored line. We have confirmed that the changes have been influenced by both the seasonal current along the Makassar beach, and the load of development and building construction in the coastal areas. These causes of coastal line changes can be seen from the ground survey as the high rate of beach abrasion on one part of the beach and an accretion on the northern part of the beach (shown later in Figure 6D). Other indication of the changes is based on the changes on the grain size distribution along the coast of the study area. This study has been conducted by Rohaya et al. (2012). In her study as shown in Figure 5B, she also noticed the red marker indicates the position of lighthouse building which along with time had submerged and no longer seen from the beach.

A recent study by Sakka et al. (2012) has monitored the shoreline changes for a period of 19 years (1990 – 2008) in the delta of the River Jeneberang, Makassar. This study was conducted by evaluating sediment transport into and out of some areas defined in the coastline. The results of the 19 year shoreline simulation showed that there was a tendency of abrasion at the upsteam head land part as the wave energy tends to converge and accretion at the bay part as the wave energy tends to diverge. Abrasion mainly occurred at Tanjung Bunga (head land) where the coast has retreated by 181.1 m. Accretion occur in the bay area (Tanjung Merdeka) where the coast line has advanced to the sea by about 59.8 m. The shoreline tends to be stable when the profile is straight such as in the Barombong Coast.

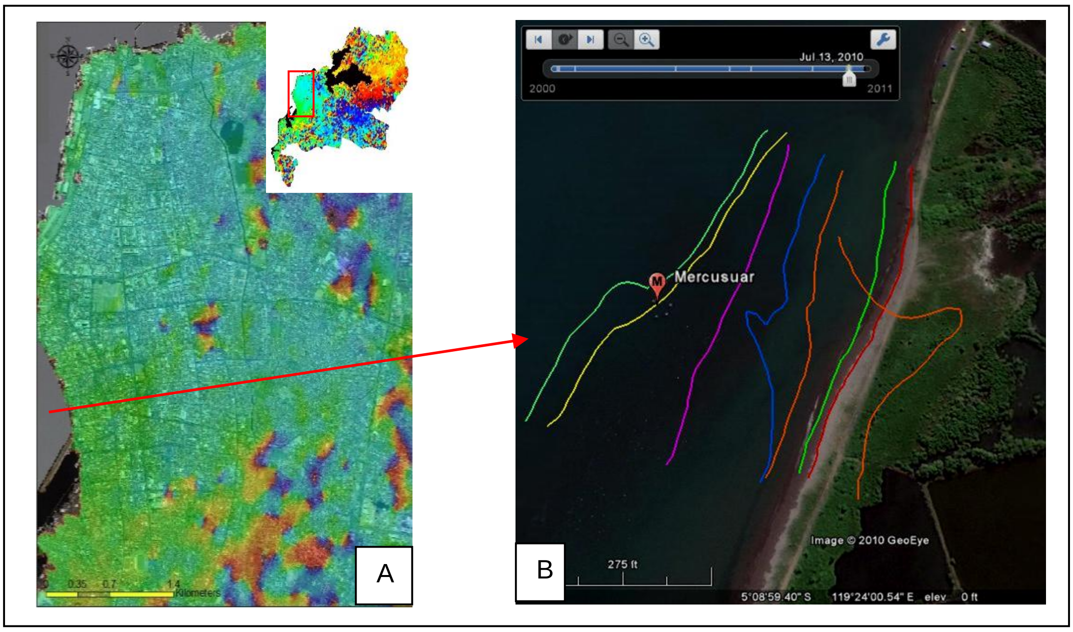

Figure 5. A The DInSAR image of the coastal areas showing indication of subsidence. B. The shoreline changes shown by the different colour lines. Red Marker indicates the location of past lighthouse that has been submerged due to the subsidence of the area.

The subset of the image in Figure 5A indicates slight subsidence at the western part of the City of Makassar and the subsidence locations are supported by the pictures taken from the ground survey Figure 6A, 6B, and 6C. In Figure 6A and 6B, the pictures indicate subsidence from the fact that the base of the house has subsided 50 cm since it was built. In Figure 6C, the picture shows that the basement of the Makassar Convention Center building has subsided 40 cm in 5 years. This subsidence is caused by various human activities such as ground water pumping and construction loads. Nevertheless, land use alterations are considered to be the most influencing factors for the geomorphologic changes observed in this city. Figure 5B clearly indicates that due to the subsidence, the shoreline has changed 25 m in 10 years or a rate of 2.5 cm every year.

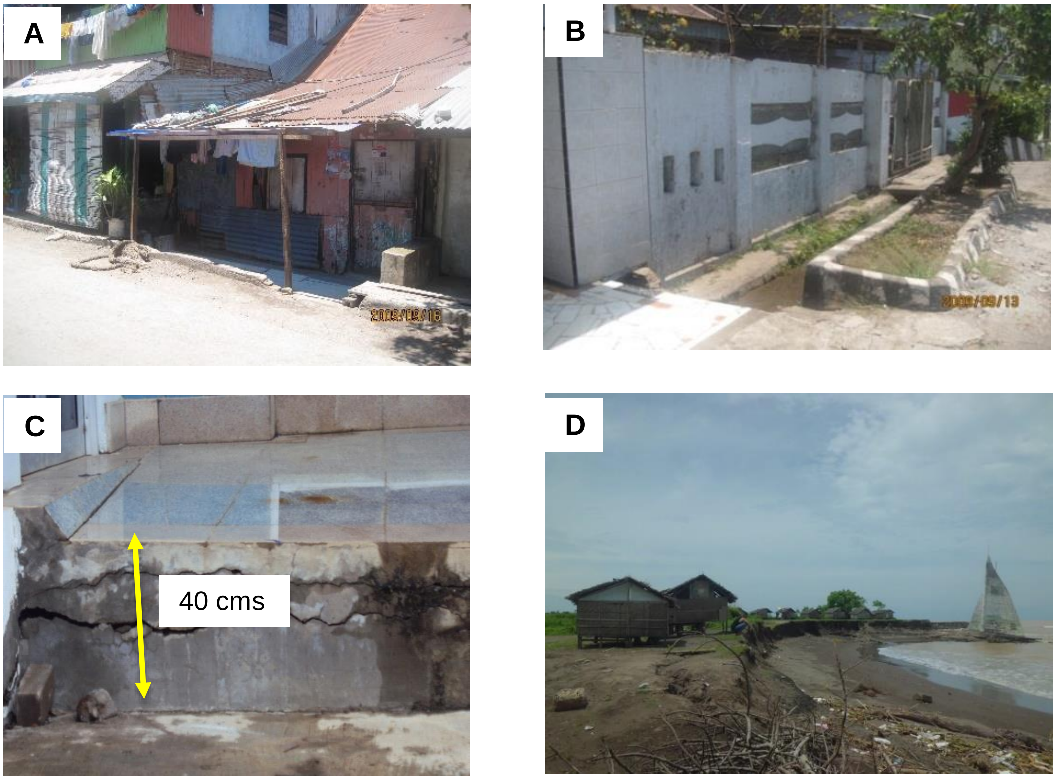

Figure 6. A-C. Ground pictures showing real indication of subsidence D. The intensity of abrasion on the coastal settlement area.

4. Conclusion and Further Work

We have shown that the application of DInSAR technique using JERS-1 data can reveal subsidence conditions in the study area. The incidences in some areas show evidence of from 5-10 cm of subsidence. The result of image processing was confirmed with GPS data and and validated with ground checking as well as the support other means of remote sensing data. Based on the coastline delineation and image overlay, we have found that the coastal areas have been experiencing subsidence with the rate of 2.5 cm/year, and for the period of 2000-2010, we measured a displacement of 25 m difference.

Further investigation can be focused on obtaining more clear indication of subsidence. In order to make further confirmation with the ground survey, the use of high resolution image is desirable. Further works can be carried out using new SAR images like ALOS PALSAR or other SAR images. Also, change studies on monthly basis may be available through the routine analysis of Landsat images.

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