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Using remote sensing and GIS for damage assessment after flooding, the case of Muscat, Oman after Gonu tropical cyclone 2007: Urban planning perspective

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1 ABSTRACT

Natural Disasters occur frequently around the world, and their incidence and intensity seem to be increasing in recent years. The Disasters such as cyclones and floods often cause significant loss of life, large-scale economic and social impacts, and environmental damage. For example, Cyclone Gonu was the strongest tropical cyclone on record in the Arabian Sea, and tied for the strongest tropical cyclone on record in the northern Indian Ocean and was the strongest named cyclone in this basin. On June 5 2007 it made landfall on the eastern-most tip of Oman with winds of 150 km/h (90 mph). Gonu dropped heavy rainfall near the eastern coastline, reaching up to 610 mm (24 inches), which caused flooding and heavy damage. The cyclone caused about $4 billion in damage and nearly 50 deaths in Oman, where the cyclone was considered the nation's worst natural disaster. Nowadays, we have access to data and techniques provided by remote sensing and GIS that have proven their usefulness in disaster management plan. Remote Sensing can assists in damage assessment monitoring, providing a quantitative base for relief operations. After that, it can be used to map the new situation and update the database used for the reconstruction of an area. Disaster management plan consists of two phases that takes place before disaster occurs, disaster prevention and disaster preparedness, a three phases that happens after the occurrence of a disaster i.e. disaster relief, rehabilitation and reconstruction. In the disaster rehabilitation phase GIS is used to organize the damage information and the post-disaster census information, and in the evaluation of sites for reconstruction. In this study, two IKONOS satellite images of Muscat, Oman have been utilized; one image before the cyclone and one after. The two images have been geometrically corrected. Change detection has been applied to identify and assess the damages. The results of this study emphasize the importance of using remote sensing and GIS in damage assessment phase as part of effective Disaster Management Plan.

2 INTRODUCTION

Cyclone Gonu, (also known as Super Cyclonic Storm Gonu) was the strongest tropical cyclone on record in the Arabian Sea, and tied for the strongest tropical cyclone on record in the northern Indian Ocean and was the strongest named cyclone in this basin (J.T.W.C., 2007). The second named tropical cyclone of the 2007 North Indian Ocean cyclone season, Gonu developed from a persistent area of convection in the eastern Arabian Sea on June 1. With a favorable upper-level environment and warm sea surface temperatures, it rapidly intensified to attain peak winds of 240 km/h (150 mph) on June 3, according to the India Meteorological Department. Gonu weakened after encountering dry air and cooler waters, and late on June 5 it made landfall on the eastern-most tip of Oman with winds of 150 km/h (90 mph), becoming the strongest tropical cyclone to hit the Arabian Peninsula. It then turned northward into the Gulf of Oman, and dissipated after moving ashore along southern Iran on June 7. Intense cyclones like Gonu have been extremely rare over the Arabian Sea, as most storms in this area tend to be small and dissipate quickly (NASA, 2007). About seven hours before passing near the northeastern Oman coastline, Cyclone Gonu began affecting the country with rough winds and heavy precipitation (Vaidya et al, 2007) with rainfall totals reaching 610 mm (24 in) near the coast (Daily News, 2007), figure (1), which caused flooding and heavy damage.

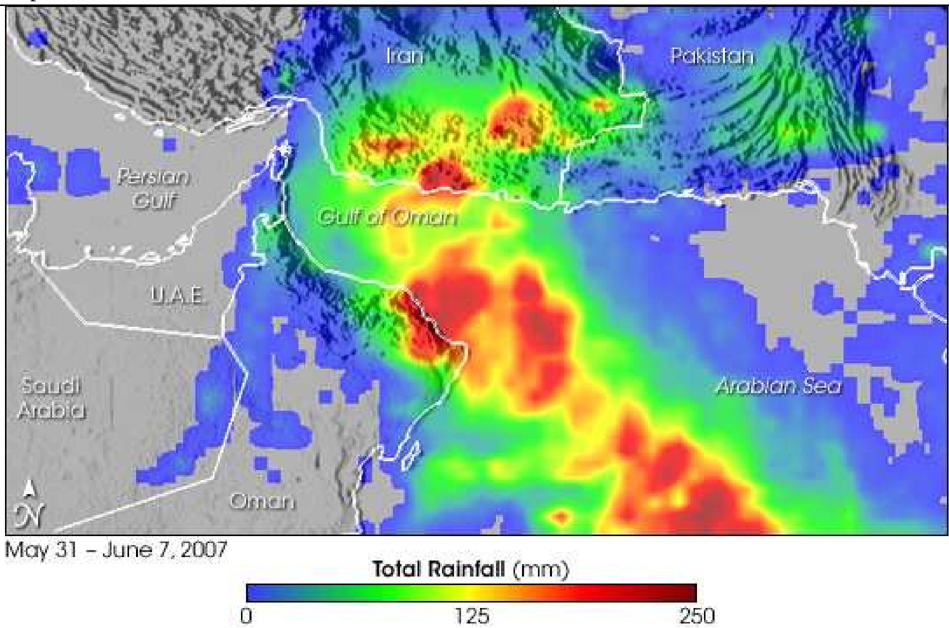

Fig. 1: Map showing rainfall totals around the Gulf of Oman between May 31 and June 7, 2007. The red areas show where rainfall exceeded 200 mm (8 inches)

The name Gonu was contributed by the Maldives, meaning 'bag made from palm leaves' in Dhivehi, the Maldivian language. Officials recommended citizens to evacuate from potentially affected areas, and about 7,000 people were forced to leave Masirah Island due to the threat of high surf and strong winds (Reuters, 2007). Overall, more than 20,000 people evacuated to emergency shelters (A.P., 2007). A state of emergency was declared for the nation (Reuters, 2007). The national weather service in Oman warned that the cyclone was expected to be worse than the destructive cyclone which hit Masirah Island in 1977 (Agencies, 2007). The Mina al Fahal oil terminal closed for over three days due to the threat of the storm (Noueihed, 2007). Omani officials closed government offices for two days, and declared a 5-day long national holiday due to the threat of the cyclone. Most businesses near the coastline were closed prior to the announcement. Authorities at the Seeb International Airport delayed all flights after 2000 UTC on June 5 due to the cyclone(Vaidya, 2007).

Gonu produced strong waves along much of the coastline (Vaidya et al, 2007), leaving many coastal roads flooded (Al-Nahdy, 2007). Strong winds knocked out power and telephone lines across the eastern region of the country, leaving thousands isolated until the lines were repaired hours later. The cyclone caused extensive damage along the coastline, including in the city of Sur and the village of Ras al Hadd at the easternmost point of the Omani mainland (Vaidya, 2007). In Muscat, winds reached 100 km/h (62 mph), leaving the capital city without power. Strong waves and heavy rainfall flooded streets and some buildings. In effort to prevent electrocutions, police workers sent text messages to residents which recommended residents away from certain streets. Little damage was reported to the oil fields of the nation (A.P., 2007) . The liquefied natural gas terminal in Sur, which handles 10 million tonnes of gas each year, was badly hit by the storm and could not be operated. According to the Oman News Agency, the cyclone killed 49 people in the country, with an additional 27 reported missing by four days after it struck the country. The damage in the country was estimated at around $4 billion (2007 USD), ranking it as the worst natural disaster on record in Oman.

3 AREA OF STUDY

Oman is located in the southeastern quarter of the Arabian Peninsula and, covers a total land area of approximately 300,000 square kilometers. Muscat is the capital and largest city of Oman; it is also the seat of government and the centre of Commercial activities in Oman. The city gave its name to the country until 1970, which was called Muscat and Oman. Muscat is located in northeast Oman, at 24°00′N 57°00′E / 24°N 57°E / 24; 57. The Tropic of Cancer passes south of the area. It is bordered to its west by the plains of the Al Batinah Region and to its east by Ash Sharqiyah Region. The interior plains of the Ad Dakhiliyah Region border Muscat to the south, while the Sea of Oman forms the northern and western periphery of the city. The water along to coast of Muscat runs deep, forming two natural harbours, in Muttrah and Muscat. The Western Al Hajar Mountains run through the northern coastline of the city. The city is situated on a cove surrounded by volcanic mountains, and it is connected by road to the west and the south. The Al Sultan Qaboos Street forms the main artery of Muscat, running west-to-east through the city. The street eventually becomes Al Nahdah Street near Al Wattayah. Several inter-city roads such as Nizwa Road and Al Amrat Road intersect with Al Sultan Qaboos Road (in Rusail and Ruwi, respectively).

The metropolitan area spans approximately 1500 km² and includes six wilayats; Muttrah, Bawshar, Seeb, Al Amrat, Muscat and Qurayyat (figure 2). According to the 2003 census conducted by the Oman Ministry of National Economy, the population of Muscat is 632,073. (M.N.E, 2003) Muscat formed the second largest governorate in the country, after Al Batinah, accounting for 27% of the total population of Oman. As of 2009, the population of the Muscat metropolitan area was 855,507 (World Gazeteer, 2009).The population density of the city was 162.

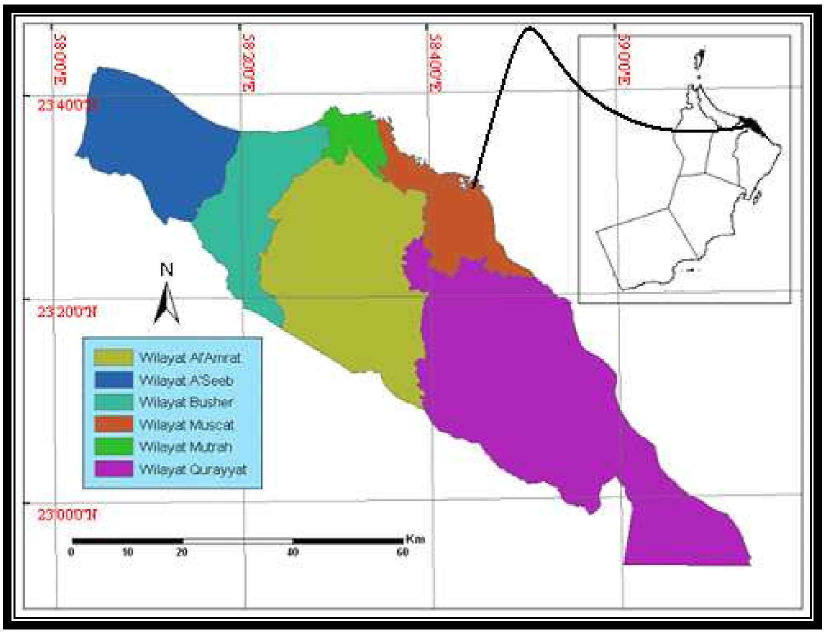

Fig. 2: Area of study (Al-Awadhi, 2009)

Since the ascension of Qaboos bin Said as Sultan of Oman in 1970, Muscat has experienced rapid infrastructural development that has led to the growth of a vibrant economy and continuous urban expansion. The city’s unusual architecture shows Arab, Portuguese, Persian, Indian, African, and modern Western influences. Annual rainfall in Muscat averages 10 cm (4 in), falling mostly in January. The climate generally is very hot, with temperatures reaching 54°C (129°F) in the hot season, from May to September.

4 GIS AND REMOTE SENSING FOR DAMAGAE ASSESSMENT

4.1 GIS and damage assessment

A Geographical Information System (GIS) has a graphic database of geo-referenced or spatial information, which is linked to the descriptive database. A GIS uses high-powered graphic and processing tools that are equipped with procedures and applications for inputting, storing, analyzing and visualizing geo-referenced information. A GIS’s capacity for data integration makes it possible to look at and analyze data in powerful new ways. A GIS is useful mainly because of its capacity to build models or representations of the real world from information in databases. It achieves this by implementing a series of specific procedures that generate still more information for spatial analysis and used to assist in problem - solving and planning. GIS is therefore important for aiding hazard prevention and for simulating the damage that would be caused in the event of a natural disaster. GIS can also be used to interpret information by creating thematic maps that show the spatial distribution of the information. These maps show spatial patterns, trends or relationships, making it easier to analyze the information. This is the case in the various successive stages of the process of assessing the damage caused by a disaster.

4.2 Remote sensing and damage assessment

Damage assessment by remote sensing can be categorized to the following phases:

4.2.1 Assessment of Flood Damage (immediately during Flood)

During floods, Remote sensing data provide timely and detailed information that are required by the authorities to locate and identify the affected areas and to implement corresponding damage mitigation. It is essential that information be accurate and timely, in order to address emergency situations (for example, dealing with diversion of flood water, evacuation, rescue, resettlement, water pollution, health hazards, and handling the interruption of utilities etc.). Some important spatial outputs produced and analyzed in real time. For example, flood extent maps, real time monitoring by remote sensing data and of damage to buildings and infrastructure Maps. Moreover, meteorological reports based on real-time remote sensing data are required to show intensity/estimates, movement, and expected duration of rainfall for the next 3 hours. Evaluation of secondary disasters, such as waste pollution can be detected and assessed during the crisis by remote sensing data as well. (Jeyaseelan, 1999)

4.2.2 Relief (after the Flood)

In this stage, re-building destroyed or damaged facilities and adjustments of the existing infrastructure will occur. At the same time, insurance companies require up-to-date information to settle claims. The time factor is not as critical as in the last stage. Nevertheless, both medium and high-resolution remote sensing images, together with an operational geographic information system, can help to plan many tasks. The medium resolution data can establish the extent of the flood damages and can be used to establish new flood boundaries. They can also locate landslides and pollution due to discharge and sediments. High-resolution data are suitable for pinpointing locations and the degree of damages. They can also be used as reference maps to rebuild bridges, washed-out roads, homes and facilities (Jeyaseelan, 1999).

5 OBJECTIVES

5.1 Identifying the damaged sites and its extent.

5.2 Assessment of the damaged sites.

5.3 Measurement the impact of disasters on the geographical environment of the affected areas.

6 METHODOLOGY

6.1 Data

In this study, two IKONOS satellite images of Muscat, Oman have been utilized; one image before the cyclone (8th January 2006) (Figure 3) and one after (12th June 2007) (Figure4). IKONOS is the world's first commercial satellite able to collect black-and-white (panchromatic) images with 82-centimeter resolution and multispectral imagery with 4-meter resolution. Imagery from both sensors can be merged to create 1-meter color imagery (pan-sharpened). Table 1 shows the characteristics of IKONOS system.

IKONOS SPECIFICATIONS	
Spatial Resolution	0.82 meter x 3.2 meters
Spectral Range	526–929 nm 445–516 nm (blue) 506–595 nm (green) 632–698 nm (red) 757–853 nm (near IR)
Swath Width	11.3 km
Revisit Time	Approximately 3 days
Orbital Altitude	681 km

Table 1: Characteristics of IKONOS (Geo-Eye 2009)

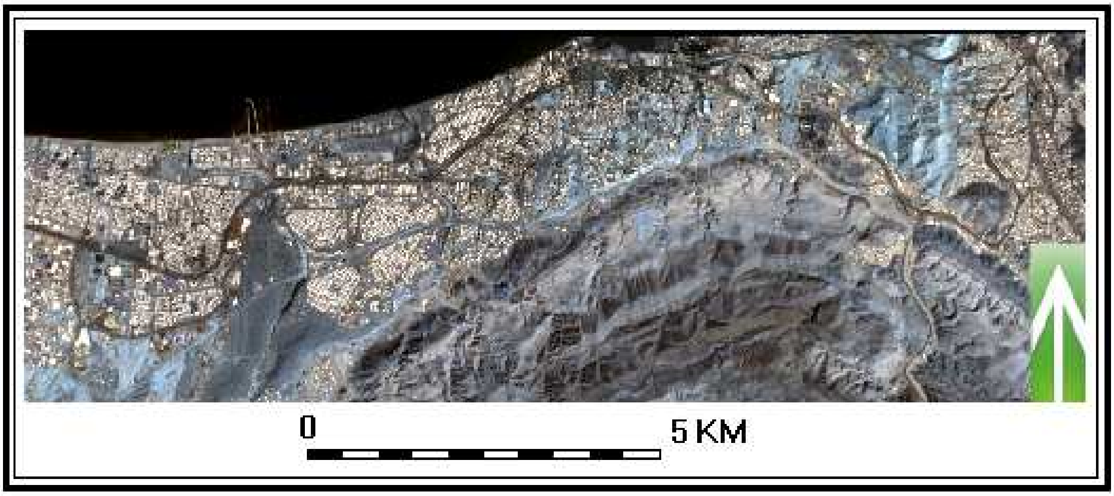

Fig. 3: Area of study before Gonu

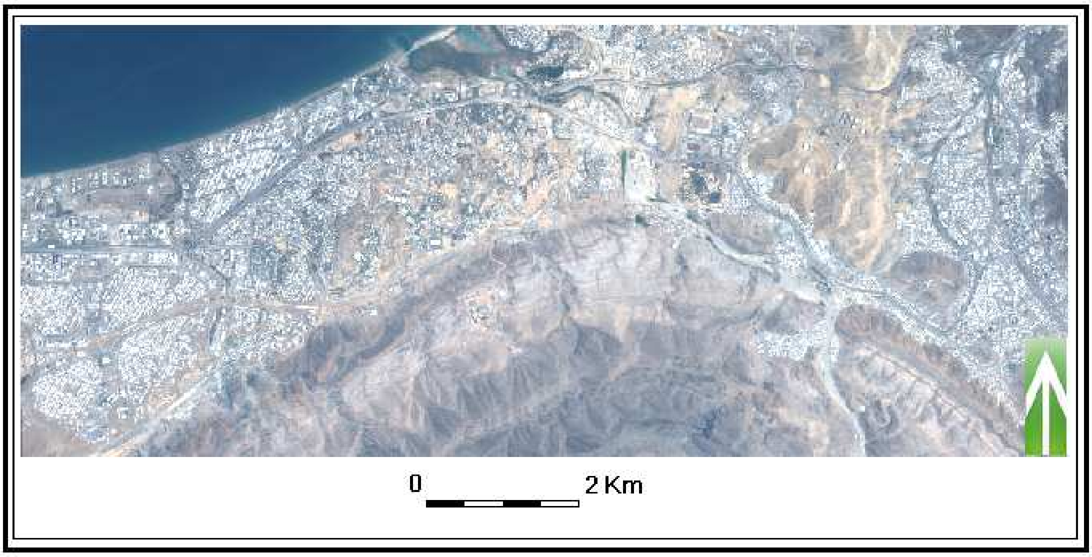

Fig. 4: Area of study after Gonu

6.2 Methods

Figure (5) summarizes the phases and methods used in this study. The two images have been geometrically corrected. Then, Areas Of Interests (AOIs) have been extracted from the images using (Subset function) in ERDAS Imagine 8.6 using visual observations depending on cyclone impacts from the recent image (after event image). Change detection technique used here to compare (AOIs) from (after event image) with their counterparts in the old image (before event image) using (Geolink function) in ERDAS Imagine. This technique can be included within "Visual Analysis" techniques where visual interpretation is used to identify the change by on-screen digitizing from images of different dates (LU et.al, 2004). This technique can be called "Geo-linking change detection" as the comparison between the images is based on their geographical locations. Areas of change were extracted and mapped using "Map Composition" tool. At the end, the area and perimeter of affected areas were calculated using "Measurement" tool in the same program.

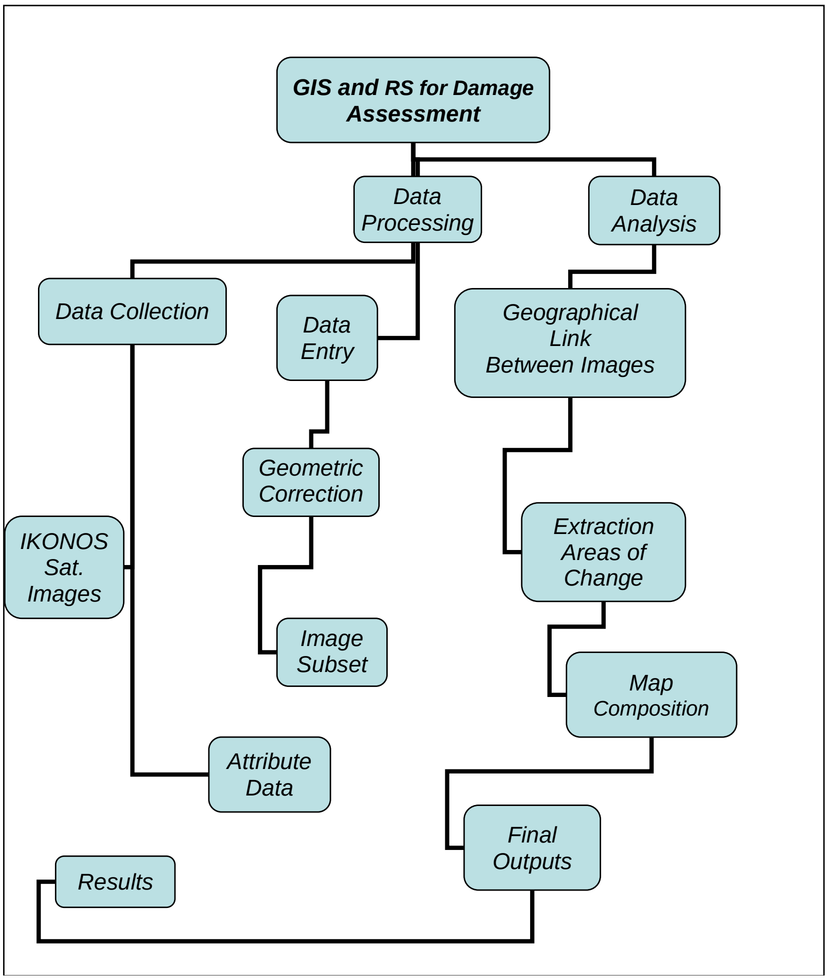

Fig. 5: The methodology used in this study

7 RESULTS

Many areas of interest (AOIs) have been extracted from the two images. However, only some of these areas will be presented on this study. Figure (6) and photo (1) illustrate a damaged part of a bridge on Alqurm area (after event image). On the second part of the figure, the bridge before the cyclone.

Fig. 6: a damaged part of a bridge on Alqurm area Bridge (left), the bridge before the cyclone (right)

Photo 1: the damaged part of the bridge

Figure (7) and Photo 2 show one of significant damages on Alqurm beach

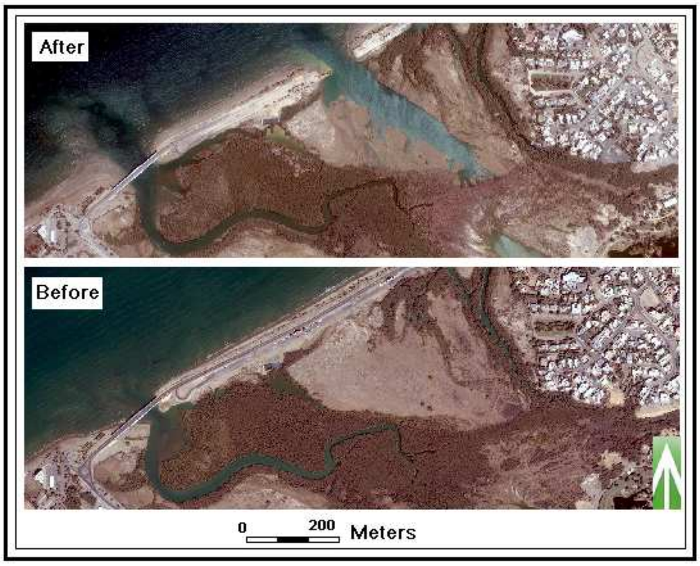

Fig. 7: significant damages on Alqurm beach

Photo (2) damages on Alqurm beach

Figure (8) shows inundated areas behind Sultan Qaboos Grand Mosque (Alghubra area).

Fig. 8: Inundated areas behind Sultan Qaboos Grand Mosque (Alghubra area)

Figure (9) shows another coastal area in Muscat

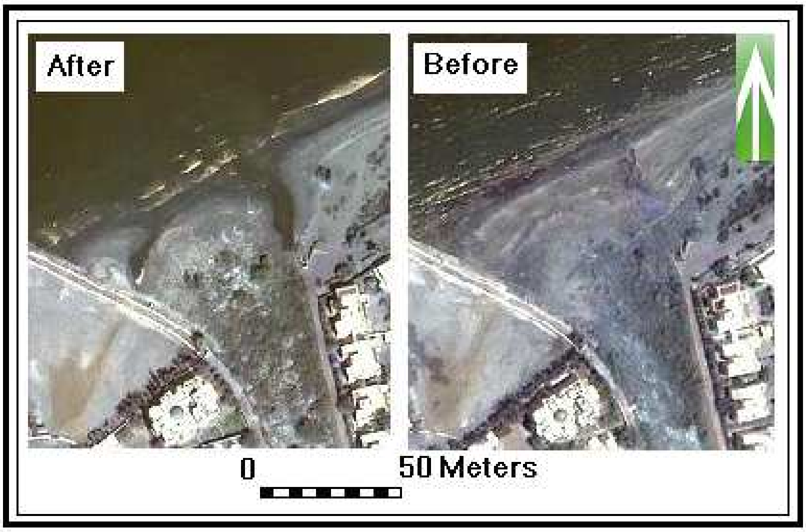

Fig. :9 Ezibah Coast

Moreover, the perimeter and total affected area were calculated as shown in table (2)

Area Name	Perimeter	Total affected Area Hectare/ (Square Meter)
Part of a danaged Bridge	163.43	0.0746 (745.70)
Alqurm Beach	1468.35	4.7285 (47285)
Behind Sultan Qaboos Mosque	1920.44	10.5153(105153)
Ezaiba Coast	383.63	0.7019 (7018.8)

Table (2) the perimeter and total area of affected locations

These quantiataive information can assist in damage assessment monitoring and it can be used to map the new situation and update the database used for the reconstruction of an area.

8 CONCLUSION

In this study, remote sensing data and techniques provided by GIS have proven their usefulness in disaster management plan especially in mapping the new situation after the disaster which help in updating the geographical database. This can be used for the reconstruction of the damaged area. GIS helped to interpret information by creating satellite based thematic maps that show the spatial diminsion of the effected areas. This will ease information analysis for successive stages of the process of assessing the damage caused by the disaster especially re-building damaged facilities and infrastructure. Insurance companies shall use this updated spatial information to settle claims. IKONOS images with its high-resolution proved usefulness for pinpointing locations and the degree of damages. Moreover, IKONOS images can be used as reference maps to rebuild bridges, washedout roads, homes and facilities.

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