

Assessing shoreline response to three submerged breakwaters at Kerteh Bay, Terengganu, Malaysia using Landsat imagery

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Abstract. As part of a project to determine the exact structural and environmental parameters governing the mode and magnitude of salient formation behind a submerged breakwater, a remote sensing technique is being adopted to assess the extent of erosion/accretion at Kerteh Bay, Terengganu, Malaysia. Multi-temporal Landsat satellite images of coarse resolution for the years of 1994, 2000, 2006, 2009 and 2012 were acquired for this purpose. The images were subsets divided into smaller areas of interest and classified using supervised classification of support vector machine. The classified image is then vectorized to extract shoreline based on waterline in each of the subset rasters images. Tidal correction were adopted to correct the waterline/shoreline to the mean sea level (MSL) datum. Comparison of corrected shorelines was carried to obtain the extent of erosion/accretion at the Kerteh Bay, Terengganu, Malaysia. It was observed that substantial accretion was observed between the years 1994-2006 at the upper part of the study area, the part between northern part and the southern part also experienced accretion but not as much as compared to northern part for the same year. Erosion was noted between the years 2006-2012 for all of the areas of the study area but the rate slowed down between the years 2009-2012 for all the areas. Slope estimated from the imageries were compared with in situ slope of the same area, this served as a validation for the method used.

1. Introduction

1.1 Background

Emergent coastal structures, such as groynes, detached offshore breakwaters, and sea walls have been successfully adopted as coastal protection measures for many decades (3, 18). This type of breakwaters is common in the US and Europe (3), and even more so in Japan, where (17) reported the completion of over 4,000 emergent breakwaters by the mid-1980s. However, these types of highly intrusive and aesthetically unappealing engineering structures are becoming increasingly unpopular among the more environmentally aware modern communities. As a result, submerged breakwaters (SBWs), which do not impair amenity or aesthetics, are becoming a preferred option for coastal protection (1, 15 and 11).



However, SBWs have rarely been adopted for coastal protection in the past and therefore, their efficacy remains largely unknown. Furthermore, enhanced shoreline erosion has been reported in the lee of the structures at several SBW projects. (15) carried out a comprehensive review on documented projects of submerged breakwater in different parts of the world, unfortunately not many of these type of project are available, from the ten projects reviewed erosion were noticed at the lee of seven (7) of the projects.

1.2 Study Area

The study area is located within a town called Kerteh in the district of Kemaman in Southern Terengganu, Malaysia, about 30 km or 20 minutes' drive north of Chukai. Kerteh is the base of operations for Petronas in Terengganu, overseeing the oil platform operations off the state's coast. Kemaman is a district of 2,536 km² area with a population of 174,876. Its geographical location is 4° 31' 38" N and 103° 28' 9" E. The stretch of the beach protected is approximately 2100 m. The study area is characterized with much of its coast to be a series of large and small hook-shaped bays, fully exposed to direct wave attack (especially during the NE-monsoon) from the South China Sea. The geomorphologic feature of Kerteh bay is such that its development is controlled by protruding headlands. Most of the bays along this region are considered to be in dynamic equilibrium; this is when constant supply of material from upcoast or within its embayment is passing through the bay and beyond the downcoast headland. The littoral drift rate, associated with the dynamically stable configuration of Kerteh Bay, has been computed to be some 210,000 m³/yr of which more than 80% is transported during the NE-monsoon period

The cause of the coastal erosion at the study area Kerteh bay, was studied by (20). Some major causes were highlighted by the researchers. The beach platform at Kerteh bay is such that there exists a continual longshore sediment transport from upcoast to downcoast, disruption of this dynamic stability may easily occur when upcoast sediment supply is (partly) cut off which can result into erosion of the coast leading to a larger indentation of the bay configuration. If the entire upcoast sediment supply is cut off, the bay would become even more indented until littoral drift ceases. Another factor identified is the cross-shore sediment transport, although it was reported that this factor doesn't have as much effect as the longshore sediment transport. The direction and intensity of this transport phenomenon are ruled by the wave steepness, geometry of the seabed slope and the size of the seabed particles. The beach will accrete at moderate wave conditions and recede under severe wave attack

The third factor is the supply of sand by S. Kerteh river discharge. Unlike the larger rivers in the region such as S. Terengganu, S. Dungun and S. Kemaman, it was found that S. Kerteh River only drains a very limited catchment and it is unlikely that its sediment yield will be of significance for beach stability. The last factor identified to be affecting the stability of the coastal area within Kerteh Bay is considered to be the human activity such as removal of natural dune systems and vegetation.

An interesting phenomenon that affects the coastal erosion at Kerteh Bay is the upcoast sediment supply from Paka Bay which is largely transferred into Kerteh Bay through offshore bar bypassing at the northern end of the bay. The "supply point" on to the coast of Kerteh Bay is located immediately updrift from Rantau PETRONAS Complex, which makes this coastal stretch particularly vulnerable to any disruption of the equilibrium situation. This is reflected in the shoreline mapping from 1966 to 1987; the observed erosion over this period would indicate an average deficit in the upcoast sediment supply of some 40,000 m³/yr. The causes and persistency of this deficit is unknown, but quite likely originate from S. Kerteh influence (disruptive of bar bypassing) and from shore developments within the upcoast Paka Bay, undertaken since the late sixties.

From the findings of the cause of coastal erosion at Kerteh Bay, (20) proposed some mitigation measures. By careful examination of the geomorphologic situation of the Kerteh Bay and acknowledging the cause of erosion at the Rantau Petronas Complex, various defense schemes were proposed. An artificial supply of sand (beach nourishment, perched beaches), structures to prevent waves from reaching erodible materials such as bulkheads, seawalls, revetments and offshore breakwaters and the last being structures to slow down the rate of littoral transport such as groynes (trapping the sediment) or offshore breakwaters (reducing the wave energy in the coastal zone) were all among the methods proposed.

The beach nourishment and use of three offshore submerged breakwaters were adopted for the purpose of mitigating the coastal erosion at the affected area as it the time of the study carried out by (20). Subsequently, three submerged breakwaters with beach nourishment to mitigate the coastal problem at a specific time. The solution could be considered relatively effective considering the problem at that time but no monitory survey has been carried out since the installation to evaluate the performance of these structures but erosion has been noticed at the south and north of the protected area. The objective of this study is to assess the shoreline response towards submerged breakwaters that was constructed at Kerteh Bay, Malaysia using Landsat Imagery.

2. Material and Methods

2.1 Field profile survey

Total station method of survey has been in place for quite a while. It is method of survey that involves the use of total station equipment to perform survey. In this field work, it was used to carry out beach profile survey, among the parameters that total station measures are angles, both vertical and horizontal angle and also distances, both slopes distances and horizontal distances. These parameters were adopted to compute the elevation at each point on each profile line. Figure 1 show the survey path followed with respect the SBWs installed, total of 2.6 kilometres was survey.

The equipment's used for the survey are as follows;

1. Total station (1 unit)
2. Mini-prism (2 unit)
3. Tripod (2 units)
4. 100 meter rule (1 unit)
5. Tape (1 unit)
6. Walkie talkie (2 units)
7. Staffs (2 units)
8. Prism (1 unit)



Figures 1: Survey path.



Figure 2: Survey description.

The steps of survey are as follows;

1. Identify/locate position of permanent bench marks, if none create temporary bench marks to identify each profile line.
2. Set out the equipment for survey.
3. Ensure to level the equipment properly.
4. Ensure to place the total station at a convenient position so as to capture as many profile lines as possible, if possible 3 profile lines.
5. The survey should involve at least two persons, one person operates the total station and the other moves the prisms from one spot to the other.
6. Determine the coordinate of the first bench mark, if not available use an arbitrary bench mark (NEZ: 1000, 1000, 100).
7. From the first bench mark capture the first Back sight, and record the Vertical angle, Horizontal angle and Slope distance, the equipment computes the appropriate NEZ from these values. This survey is only interested in the Z value which is the elevation.
8. Also from the first bench mark capture the first point on the first profile line Fore sight, Also record the vertical angle, horizontal angle and slope distance. This should be done for all of the point on the first profile line without change the position of the total station.
9. Repeat this for all of the other 25 profile lines.

2.2 *Remote sensing*

In recent years the numerous studies of quantitative aspects of coastline structure variously focused on a range of data extraction approaches that can be categorized as sensor, band and visual selection. In sensor selection, active and passive sensors are selected to delineate waterlines between water bodies and coastal zones. Although synthetic aperture radar (SAR) images have advantages over those based on other approaches, including near infrared (NIR) and shortwave infrared (SWIR), optical imagery is effective depending on broad ground coverage, cost-effectiveness and availability of data (1996: (23)). Thus, many studies have assessed the relative merits of various sensors (22) Landsat series are useful for deriving waterline information because they represent long-term historical data and provide repetitive, synoptic multispectral images with global coverage (23) Landsat series are useful for deriving waterline information because they represent long-term historical data and provide repetitive, synoptic multispectral images with global coverage (23). This study involves data collection over a global coverage and repetitiveness is of necessity. Such imagery characteristics were found by the adoption of Landsat imagery.

2.2.2 *Waterline extraction*

In the present study 15 cloudless satellite images from LANDSAT satellites were collected from the years 1996, 2000, 2006, 2009 and 2012, three images were collected for each of the year. The spatial resolution of the images used is 15 m, Table 1 contains the shooting time of the image, image resolution, image precise date and day, tidal level corresponding to each of the scenes.

2.2.3 *Determination of shoreline*

To determine the shoreline a sophisticated method called one-line model or shoreline change model is adopted. The method of shifting waterlines to the tidal-datum-based shoreline position on mean sea

level (MSL) is based on the concept of one-line model for shoreline evolution and called one-line shift method (OSM). It is assumed that beach moves offshore or onshore with one bottom profiles. Fig 3 shows three beach profiles at three different times: t_i ($i = 1, 2, 3$). At time t_i , the waterline is located at x_i , away from the origin of the transformed coordinates, the corresponding water depth is h_i above or below MSL. When the sea surface is at MSL, the MSL-datum-based shoreline is located at z_i away from the origin. Figure 3 illustrates an example of a beach profile moving from the right to the left.

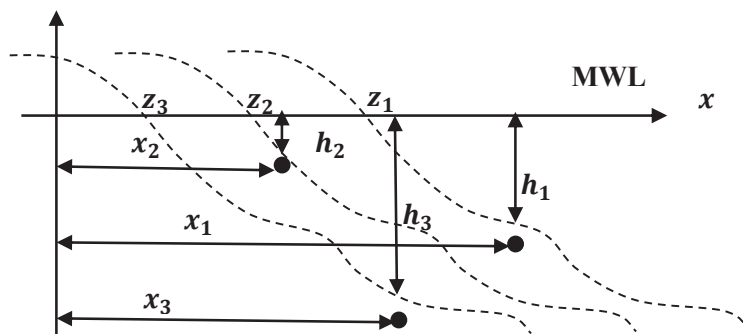


Figure 3: Beach profiles at three different times and symbolic notation.

If the extracted waterline from satellites images at time t_2 and t_3 are located at x_2 and x_3 , respectively, $x_3 > x_2$. Extracted waterline without consideration of tidal effect imply that the beach moves from left to the right. This inference conflicts with assumption for Figure 3 shifting the extracted waterlines to the MSL-datum-based shoreline position is necessary to accurately estimate the beach movement.

Table 1: Satellite imagery descriptions with corresponding tidal levels.

Masters Image					Slave Image				
Date	Time	Sensor	Resolution (m)	Tidal level (cm)	Date	Time	Sensor	Resolution (m)	Tidal level (cm)
4/11/1994	10:42:09 A.M	TM	15	-23	4/11/1994	10:42:09 A.M	TM	15	-23
					3/7/1995	11:15:00 A.M	TM	15	-50
					9/2/1995	11:15:00 A.M	TM	15	70
2/7/2000	10:56:10 A.M	TM	15	-21	2/7/2000	10:56:10 A.M	TM	15	-21
					4/3/2000	11:14:29 A.M	TM	15	-35
					5/8/2001	11:12:01 A.M	TM	15	85
9/11/2006	11:11:34 A.M	TM	15	43	9/11/2006	11:11:34 A.M	TM	15	43
					10/29/2006	11:11:43 A.M	TM	15	-23
					4/17/2005	11:10:27 A.M	TM	15	-10
2/7/2009	11:11:50 A.M	TM	15	-115	2/7/2009	11:11:50 A.M	TM	15	-115
					7/1/2009	11:12:24 A.M	TM	15	17
					1/22/2009	11:11:45 A.M	TM	15	-87
4/20/2012	11:16:09 A.M	TM	15	27	4/20/2012	11:16:09 A.M	TM	15	27
					5/22/2012	11:16:39 A.M	TM	15	103
					7/23/2011	11:15:31 A.M	TM	15	37

Based on past research it is reasonable to assume that a beach face has an approximately uniform slope. The bottom slope, s , is defined by

$$\frac{h_i}{x_i - z_i} = s, (i = 1, 2, 3) \quad (1)$$

In which the subscript i denotes the physical quantity at time t_i and both s and z_i are unknown at this point. It is assumed that the beach moves at a steady velocity during a period of t_1 to t_3 . The moving speed of the beach profile can be expressed as;

$$v = \frac{z_j - z_i}{t_j - t_i} = \frac{\Delta z_{ji}}{\Delta t_{ji}} \quad (i, j = 1, 2, 3) \quad (2)$$

Two different times, between t_1 and t_2 and between t_2 and t_3 , are chosen. Equating the moving speeds during two time differences and then inserting the result into eq (2) gives the bottom slope as

$$S = \frac{\Delta h_{32} - \frac{\Delta t_{32}}{\Delta t_{21}} \Delta h_{21}}{\Delta x_{32} - \frac{\Delta t_{32}}{\Delta t_{21}} \Delta x_{21}} \quad (3)$$

Where the operator means the difference of a physical quantity from time t_i to t_j . Substituting eq. (3) into eq (2) yields the MSL-based shoreline position

$$Z_i = x_i - \frac{h_i \left(\Delta x_{32} - \frac{\Delta t_{32}}{\Delta t_{21}} \Delta x_{21} \right)}{\left(\Delta h_{32} - \frac{\Delta t_{32}}{\Delta t_{21}} \Delta h_{21} \right)} \quad (4)$$

When three sequential waterlines are detected at t_i ($i = 1, 2, 3$), the corresponding offshore distance x_i is known and the water depth h_i is obtained by eq. (1). The MSL-datum-based shoreline position is finally determined by eq. (4). A non-dimensionalized ratio of two time difference on Eqs. (3) And (4) shows that the unit of t is independent of estimating the shoreline position. Time unit in the calculation of time difference is hour. When the shoreline positions determined by the proposed OSM at times t_i are obtained, the movement of the beach is then evaluated for further investigation. (2)

3. Results

As stated in Section 2, Landsat multi-temporal images of the study area with 15 m spatial resolution were acquired. These images are 15 m resolution of panchromatic form. Figure 4 shows the unprocessed image. Three images each were acquired for the years 1994, 2000, 2004, 2009 and 2012. The three images in a year were required for the purpose of correcting tides for each year. Using the OSM method of tidal correction it is required to use images of a particular area taken at most six months apart, this will ensure the images used for the tidal correction are taken at a time when there is no or negligible change in bottom slope.

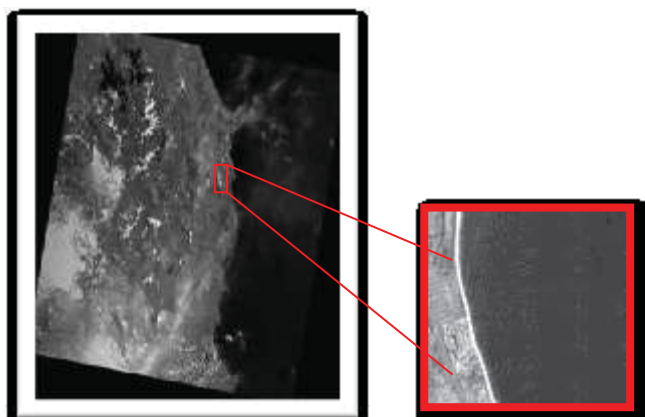


Figure 4: Showing sub-setting of unprocessed image.

After the application of tidal correction using the OSM method, changes were evaluated using the overlaying method. This was performed in the ENVI 4.9 software. The graphic representation of this process is as shown in Figure 5.

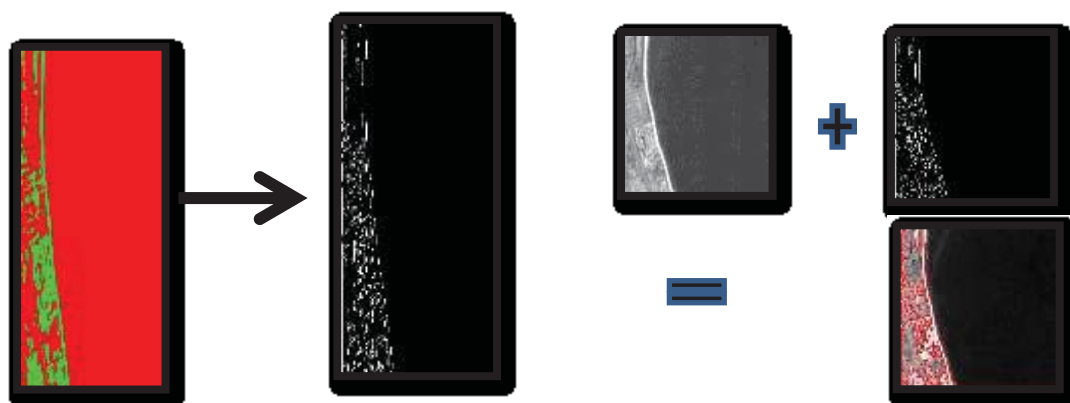


Figure 5: Vectorization of classified images and overlay of vector on raster image.

As part of the process to obtain the key parameters that govern the mode of shoreline change and the magnitude at the lee of a breakwater, beach profile surveys were also conducted. The study area was divided into three major parts for the sake of analysis of the beach survey. The divided study area consists of a staff quarters, a golf course and a school. The staff quarters is situated at the northern part of the study area, the golf course is in between the staff quarters and the school. The school can be regarded as situated at the southern part of the study area. Figures 5 through 7 shows graphical representation of analysis of erosion that occurred at the staff quarters, golf course and school respectively as obtained from the remote sensing analysis.

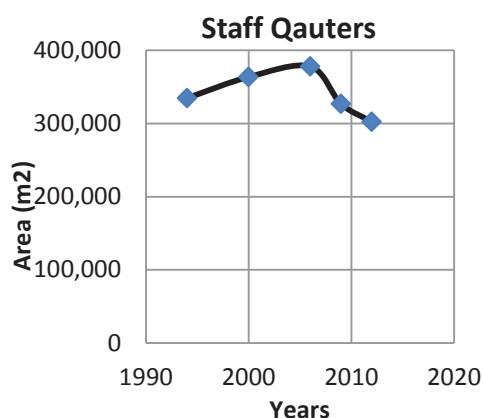


Figure 5: Showing erosion at the staff quarters.

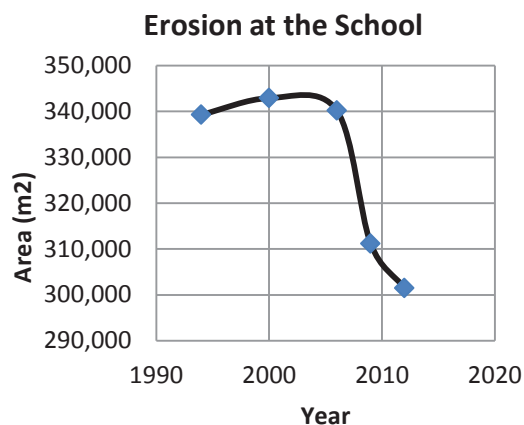
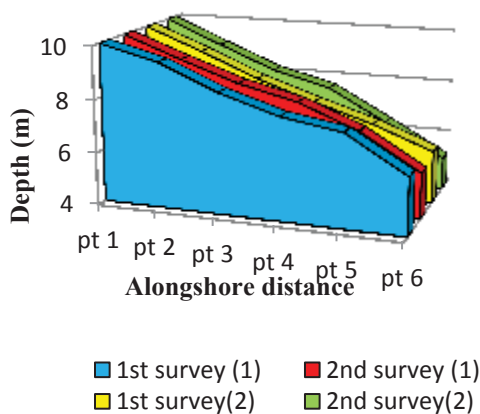
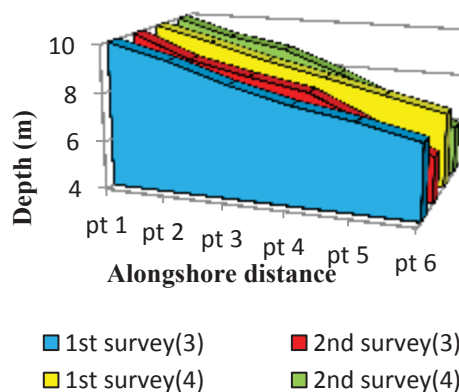


Figure 6: Showing erosion at the school.



Figure 7: Showing erosion at the Golf course.

Results from the beach profile survey conducted at the study area are presented in Figure 8 through 12. These plots show a comparison of survey results conducted at different times.

Figure 8: Plots of survey line 1 & 2 for 1st and 2nd surveyFigure 9: Plots of survey line 3 & 4 for 1st and 2nd survey

The study area was divided into 60 survey lines with survey lines 50 meters apart. Six points on each survey line were surveyed for the 1st and 2nd survey exercise. Then these points are compared in plots as shown in Figures 3.4 through 3.8. This comparison shows the extent of erosion or accretion between the 1st and 2nd survey exercise.

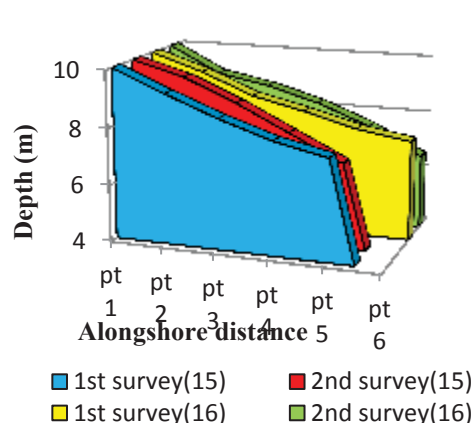


Figure 10: Plots of survey line 15 & 16 for 1st and 2nd survey

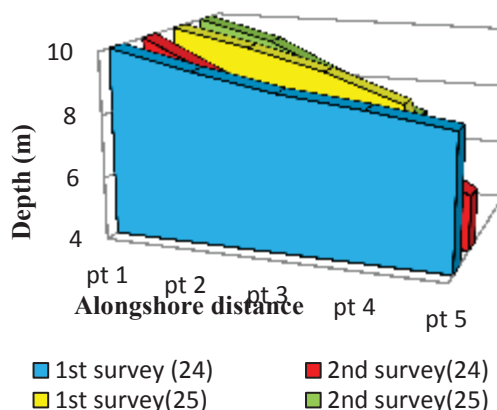


Figure 11: Plots of survey line 22 & 23 for 1st and 2nd survey

While Figures 8 and 9 shows plots of surveys line towards the southern part of the study area, Figure 10 shows plots of survey somewhere in between the southern part (school) and the northern part (staff quarters).

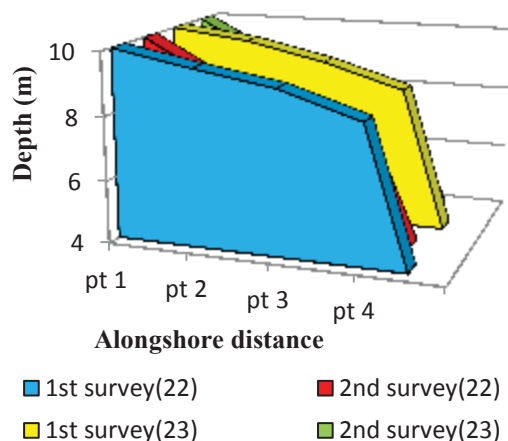


Figure 12: Plots of survey line 24 & 25 for 1st and 2nd survey

Figure 12 show plots representing line 22, 23, 24 and 25, these are the survey lines at the northern part of the study area, taken just in front of the staff quarters in the study area. To complement the graphical plots of the two surveys carried out on the study area, pictures were taken during the two surveys. A close look of the pictures amplifies the results obtainable from the plots of the surveys. Figures 13, shows pictures of the study area during the first survey and Figure 14 shows pictures of the study area during the second survey.



Figure13: Pictures of 1st survey



Figure 14: Pictures of 2nd survey

4. Discussion

4.1 Remote sensing

Landsat images acquired were processed as described in Section 2. The tidal correction was done using the OSM method as described in Section 2. The results obtained by processing these medium Landsat images indicate erosion and accretion were taken place at different years at the three different parts of the study area.

It was found that accretion occurred at the Staff Quarters, which is the northern part of the study area between the years 1994-2000, the area affected by accretion can be about 28,800 m² of area. Between 2000-2006, there was also accretion at the same area but lesser intense than that of 1994-2000. The area affected was about 14,400 m². In the year 2009-2012 erosion of magnitude 51,075 m² were observed.

For Golf course area, between 1994-2000, lesser accretion was noted as compared to the Staff quarters area. The accretion covered an area about 10,800 m². At the Golf course area, accretion occurred between the years 2000-2006, covering an area 25,200 m². Excessive erosion occurred between 2006-2009 in this area. The magnitude of the erosion is about 66375 m². In the subsequent years 2009-2012 erosion of about 8235m² occurred.

In the school area, accretion was also noted between the years 1994-2000 covering an area of 3600 22 m² and unlike the other two areas (staff quarters and golf course) less erosion occurred between 2000-2006 covering an area of 2700 m². However, erosion during the years 2006-2009 and 2009-2012 were at higher rate with values of 29025 m² and 9675 m² respectively.

4.2 Field survey

The second field trip revealed an alarming erosion rate that had occurred between the period of the first and second visit. Visual observation of the site reveals more erosion occurred at the northern part of the study area as compared to the southern part of the study area. Figures 11 and 12 indicate that more serious erosion occurred at the northern part as compared to the southern part. Figures 11 and 12 are plots of the profile lines 22, 23, 24 and 25, which represent survey lines at the

northern part of the study area and Figure 8 and 9 shows plots of profiles 1, 2, 3 and 4, which represent profile lines at the southern part of the study area. The erosion rate in the area between the northern part and the southern parts can be considered as moderate. More erosion was found in the northern part as compared to the southern part as depicted in Figure 10.

5 Conclusion

It can be concluded that erosion is still occurring at the study area. Over a period between March, 2012 and July 2012 a reasonable amount of erosion had occurred at the protected area (study area).

The Landsat images indicate that substantial accretion occurs at the staff quarters and golf course between the years 1994-2006. Less accretion was found at the school area as compared to the staff quarters and golf course areas for the same period. Erosion was more intensive between the years 2006-2012 for all of the areas but the rate slowed down between the years 2009-2012 in all of the three areas. Landsat imagery was found to be useful in the assessment of the erosion rate the study area.

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