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# Modelling and Assessment of Coastal Changes at Golspie Beach, Scotland, UK; An Integration of Terrestrial Laser Scanning and Digital Photogrammetric Techniques, for an Effective Coastal Land use Management

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## ABSTRACT

Coastal environments globally are recognised for their highly dynamic and unstable nature. The twin processes of erosion and accretion are constantly changing the face of the coastal environments. The Golspie beach situated in Sutherland, Highlands of Scotland is not spared from these processes which have been attributed to natural and anthropogenic factors. To minimise the effects of the rampaging erosions, beach sand feeding has been proposed to protect a section of the beach. To evaluate the success of the proposed project a high resolution digital terrain model (DTM) of the current position of beach in 2014 was necessary. This was achieved with the use of terrestrial laser scanning technique to acquire highly dense point cloud with a 5cm point spacing or resolution over a 1km length of beach. As part of the aims of this study the changes in the beach between 2013 to 2014 was assessed using photogrammetric ally generated DTM from 2013 aerial photographs and DTMs of 2014 from terrestrial laser scanning techniques. These DTMs were used to assess the height and volumetric changes at the study area. The results from the change analysis revealed areas with significant loss and gains in height. Some sections were observed to have experienced height loss of approximately 0.25m to 1.5m especially around the frontage of the south end of the golf course and a section at the frontage of the Kart track. However the trend of height change recorded revealed more of gains than losses. From the volumetric analysis performed the areas with losses in sediments were highlighted. A total change of approximately 30,129.4m3 in sediment volume of the entire study area was recorded out of which the loss and gain represents 30% and 70% respectively. Overall a net gain of approximately 11,929.6m3 was recorded from the sediment budget of the entire beach with a southward movement of these sediments. The general outcome from the study revealed the success of using both techniques in beach studies, as all the aims and objectives of the study was achieved.

**Keywords:** Coastal change, Terrestrial Laser Scanning, Digital Photogrammetry, DTMs

## I. INTRODUCTION

Coastal environments changes continuously as a result of natural and anthropogenic factors and the temporal changes can range from hours to decades. These changes occurs both on a short and long-term basis depending on the morphology and material constituents of the coast in the area. Factors such as storm events and engineering activities can lead to short-term changes (Chatenoux & Peduzzi., 2006; Burak et al. 2004) while long-term changes can be induced by sea-level rise (Thom & Cowell., 2005).

This is the case with the Golspie coast situated at the Sutherland, Highland in Scotland, which lies on the North Sea coast Figure 1. There have been documented evidences of changes on its coast. One of such was reported in Hansom et al. (2013), which shows that the area has been experiencing coastal erosion Figure 2. These changes have been attributed to natural factors such as, storm waves, sea-level rise and also due to human interferences with the beach natural replenishing processes.

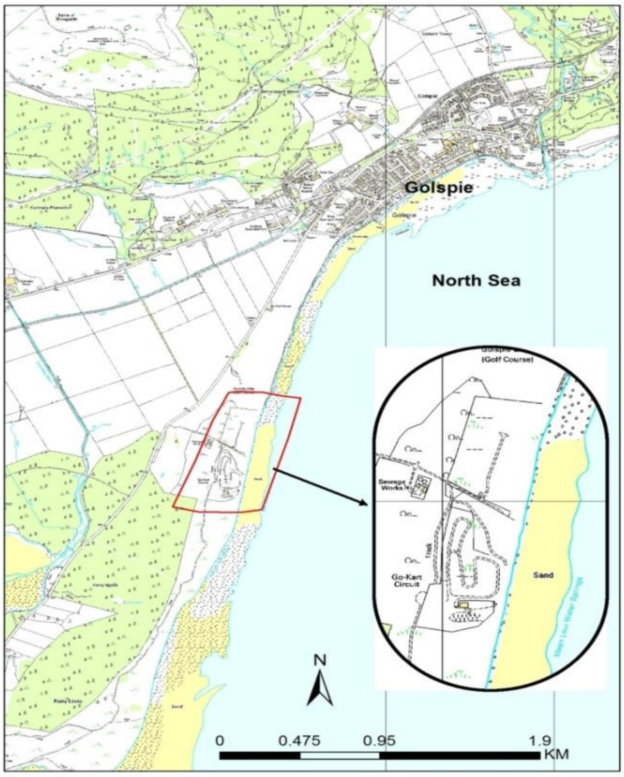


**Figure 1.** Study location Map showing the area of study (Ordinace Survey, EDINA Digimap Service (http://edina.ac.uk/Digimap) 19/08/14).

The Golspie beach is characterized by bedrock and boulder outcrops at the north end and backed by emerged marine sands and gravels which have been deposited over a period of relatively higher sea level, some 6,500 years ago (Hansom et al., 2013). Attempts have been made, albeit unsuccessfully to minimize the effect of erosion on the beach. Most of these schemes dated back to 1979 when a demolished railway bridge in Golspie was used to protect the coastal edge below the golf course.

**Figure 2.** Photo of the south end of the golf course eroding (Hansom et al., 2013)

Some attempts have been made to minimise the effect of erosion on the beach but this has really not yielded much of the desired results **Figure 3**. Instead it creates more problems to areas that are without protections (Hansom et al., 2013).

**Figure 3.** An example of some of the protection schemes such as gabion baskets at the 7th tee. Photo captured 19th June, 2014 by author.

Several techniques exist for assessing of changes in the beach environments. Some of these techniques include direct measurement of changes from electronic distance measurement (EDM), global navigation satellite system (GNSS), terrestrial laser scanning (TLS), aerial photography, synthetic aperture radar (SAR), light detection and ranging (LiDAR) and satellite imageries.

The Local Council authority at Golspie town proposed, nourishment of the beach by sand feeding to protect a section of the beach. In other to monitor and assess the effectiveness of the project, terrestrial laser scanning was required to capture highly dense point cloud data showing the present state of the beach before the project. This approach has been used effectively for beach assessment at several other locations and has yielded satisfactory results, but this was the first time it is been used at the Golspie beach.

Photogrammetric technique was also used in this study to generate a digital terrain model (DTM) of 2013 which was used alongside the TLS DTM of 2014 to assess the present changes at the beach.

## II. METHODS AND MATERIAL

### 1.1 Data Used

The study is based on two major sources of data which are from aerial photographs flown 19th February 2013 and terrestrial laser scanning executed on the 19th June 2014.

### 1.1.1 Aerial Photography Data

The aerial photographs were flown at a very low altitude and hence its spatial resolution was very high.


**Figure 1.** Aerial photographs of Golspie beach used for study flown 19th Feb. 2013.

### 1.1.2 Terrestrial Laser Scanning Data

The scanning data was acquired directly from the field at the study location over an approximately 1km of length with the use of time-of-flight scanner Leica ScanStation C10 (figure 5) on the 19th of June 2014. The instrument specification is shown in Table 1 below.

**Figure 2.** Leica ScanStation C10 a time-of-flight scanner in operation

**Table 1**. Leica Scan Station C10 specifications

| | |
|---|---|
| **Range** | 300m at 90% albedo or surface reflectance |
| **Scan Rate** | 50,000 points/sec |
| **Position Accuracy** | 6mm |
| **Distance Accuracy** | 4mm |
| **Angular Accuracy** | $\pm$12” arc-sec |
| **Scan Resolution** | 0 – 50m: 4.5mm |
| **Field of view** | 360$^o$ (maximum) Horizontal |
| | 270$^o$ (maximum) Vertical |

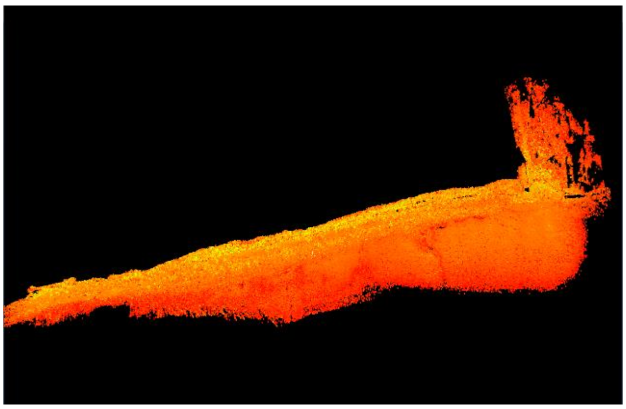

**Figure 3.** Acquired point cloud data of the beach with TLS equipment

## 1.2 Software Packages Used

The software packages used for this study were selected based on their suitability for the various task to be executed. **Agisoft Photoscan** software for the photogrammetry data processing, **Leica Cyclone 8.1** was chosen for the editing of the point cloud data acquired from the field and **ESRI ArcGIS 10.2.2** was used for the spatial analysis and measurement of the changes.

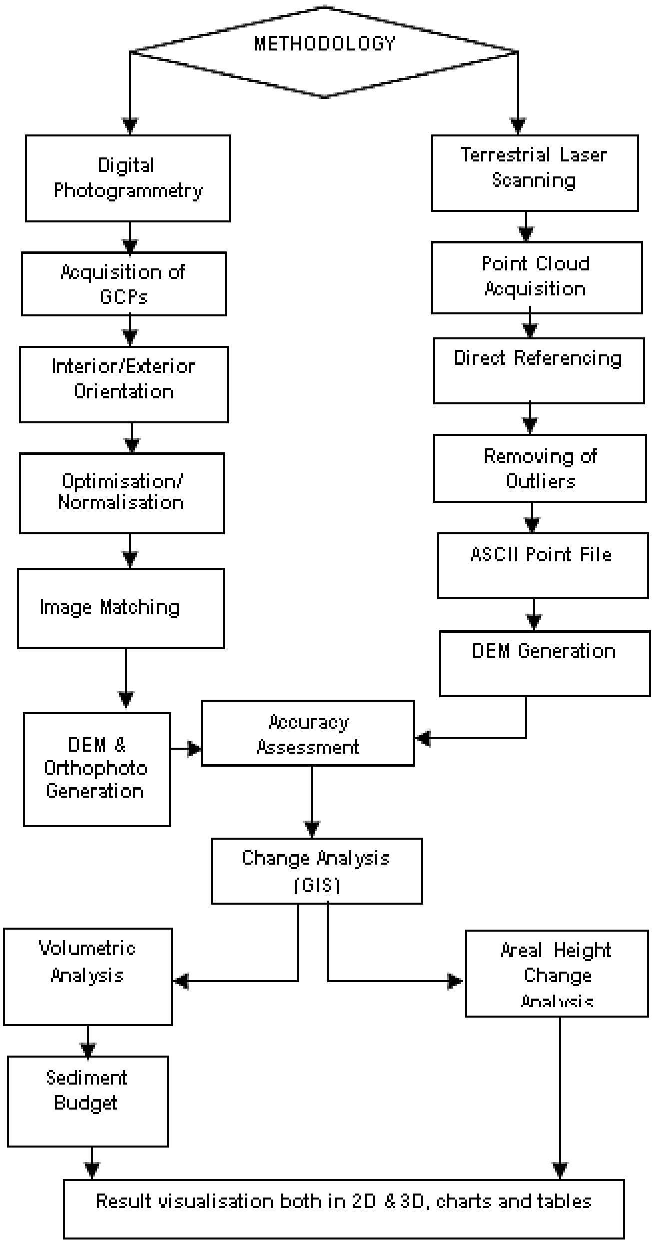


**Figure 7.** Flowchart of methodology for the study showing combined photogrammetric and terrestrial laser scanning techniques for coastal change analysis.

## 1.3 Digital Photogrammetry

Photogrammetry is the science and technology of extracting useful spatial and geometrically reliable information from photographs (Lillesand et al., 2008). Digital photogrammetry involves the use of digital raster photographic image rather than the traditional hardcopy images (Lillesand et al., 2008).

### 1.3.1 Acquisition of Ground Control Points (GCPs)

GCPs are points whose positions are known on a chosen reference coordinate system and that can be readily identified on the photographs (Grussenmeyer and Al Khalil, 2002). GCPs determine the accuracy and quality of the extracted spatial information from the images (Lillesand et al., 2008).

Ground controls were acquired from the study location using Leica RTK GNSS with a quoted horizontal and vertical accuracy of 1cm and 2cm respectively. A total of 13 GCPs were acquired for the exterior orientation process and also for check points.

Acquiring GCPs in beach terrains has always proven to be a difficult task, owing to the lack of image textures which is common to beach terrains (Mills et al., 2005, Hansom et al., 2011).

### 1.3.2 Interior/Exterior Orientation

**Interior orientation (IO)** describes the internal geometry of a camera which includes principal distance, principal point, and lens distortion parameters (Börlin & Grussenmeyer, 2013). This process is necessary to determine the transformation parameters of the camera in order to transform the pixel coordinates to photo-coordinates.

**The exterior orientation (EO)** determines the position and orientation of the camera on the ground at the time of exposure (Börlin & Grussenmeyer, 2013). This process is very important as it greatly improves the accuracy of the reconstructed surface.

The workflow in the DPWs used for this study required within 10-15 GCPs equitably distributed within the photographs.

With the use of place makers the GCPs were added to the images to enable the exterior orientation (Figure 7) in the Photoscan DPWs.


**Figure 4.** External orientation process showing the distribution pattern of GCPs

### 1.3.3 Optimisation/Normalisation

This process was implemented on the four photographs used for the project and 8487 tie-points were generated to transform every other point on the images, given it a defined 3D coordinate system. The GCPs used for the process were acquired in OSGB36 National Grid coordinate system. This enabled every pixel to be normalised to the same coordinate system.

### 1.3.4 Image Matching

Digital photogrammetry relies on image matching algorithms to match stereo images for a three-dimensional reconstruction of terrains (Qin et al., 2003). Photoscan uses the greedy and bundle adjustment algorithms for implementing these procedures. Dense point clouds from the optimised four images were built using these algorithms. The successful matching of these images together enabled the reconstruction of a 3D surface using the 3D Delaunay polygonal mesh algorithm based on pair-wise depth map computation (http://www.agisoft.ru/forum/index.php?topic=89.0).

### 1.3.5 Accuracy Assessment

The accuracy of the exterior orientation process needs to be assessed to be sure the results are within acceptable limits and as such fit for the purpose of the study.

The accuracy of the optimisation procedure can be assessed by the root mean square error (RMSE) of every interpolated point in the model (Lim et al., 2005). But this cannot be possible as the points could be over millions hence the accuracy of independent check points that are not used during the orientation process are best suitable for such assessment as mentioned in Gooch and Chandler (2001).

This approach was adopted to assess the rmse of the image processing results. The independent check points that was not used for the orientation process was used to assess the accuracy of the outputs.

### 1.3.6 Generation of DEM/Orthophoto

Generation of digital elevation models (DEMs) and orthophotos are usually the final process in the photogrammetric workflow. DEMs are continuous surfaces of evenly spaced heighted points, formed by surface matching algorithms.

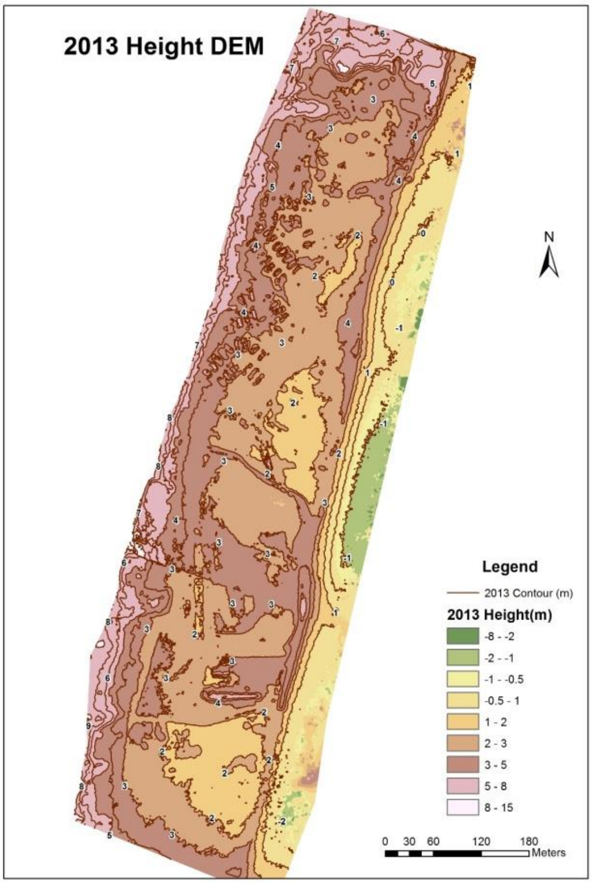


**Figure 9.** Photogrammetric generated DEM from aerial photograph flown 19th February, 2013

Photoscan uses the 3D Delaunay polygonal surface techniques to create triangulated mesh with the point clouds. During this process points within defined thresholds are used for the correlation to produce a surface. However, the final generated DEMs may contain areas of unsuccessful correlation which subsequently distort the surface, creating areas of occlusion (Lim et al., 2005).

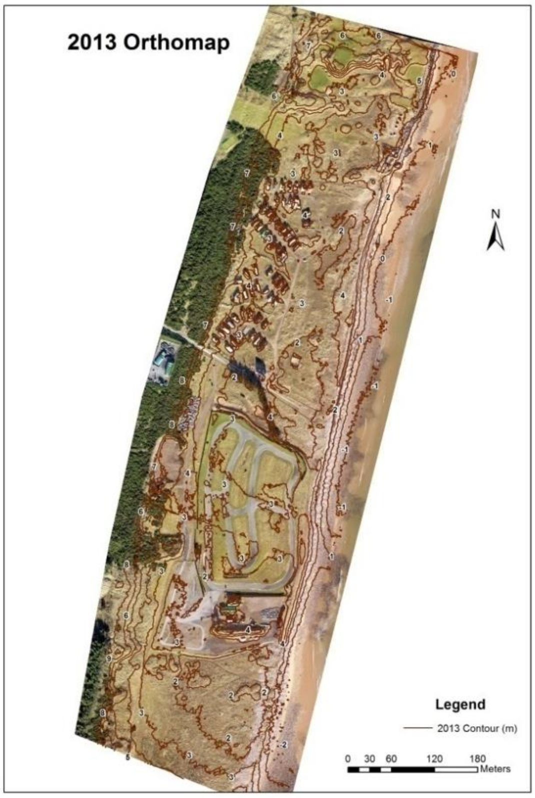


**Figure 10.** Orthomap with contour generated from aerial photographs flown 19th February, 2013

## 1.4 Terrestrial Laser Scanning (TLS)

TLS emits laser beams to an object or target and the time it takes for the reflected light beams to return to the scanner sensor are measured to determine the distance. The horizontal and vertical angles are also measured from the objects to the scanner with the centre of the scanner as the origin (Soudarissanane and Lindenbergh, 2012).

Terrestrial laser scanners are of two types, categorised based on their mode of operation. These are the time-of-flight and Phase base scanners.

### 1.4.1 Point Cloud Data Acquisition

The acquisition of point cloud requires a careful consideration of the user requirements for the data, as this would influence the kind of scanner to be employed, the point spacing or resolution, the range to the target as well as the scanning geometry with emphasis on the incidence angle which influence the quality of the scanned data (Soudarissanane et al., 2009).

A total number of 24 scans were performed at an approximate spacing of 35m between setups. A resolution or point spacing of 5cm and 25m point distance from the scanner to the targets was chosen. This number was sufficient for a full coverage of the study area.

**Figure 11.** Leica ScanStation C10 acquiring point cloud at the study site

### 1.4.2 Registration/Geo-referencing

Registration aligns several scans that have been captured at a site by linking them together on a common coordinate system. A transformation of the scanner local coordinate system to a user defined coordinate system is performed on the scanned data using different algorithms. Both indirect and direct methods exist for registering different scans together.

The direct scan registration method was used for this study to transform the local scanner coordinates to a 3D real world coordinate system. The start point of the scanner position and the target position were determined by RTK GNSS. This two known points gave orientation to the scanner, using the traversing method. Hence the scanner local coordinate was transformed to the input coordinates which was in OSGB36 coordinate system using RTK GNSS.

The direct referencing method used, removed the need for a post registration of the scans performed on the field.

### 1.4.3 Removal of Outliers (Noise)

Terrestrial laser scanners capture every object within its line-of-sight. This makes it difficult to control the data captured. This unwanted data or outliers need to be removed from the rest of the data before it can be used. Outliers deviate from the rest of the data.

Manual technique was used to remove the outliers from the data in this study since the outliers were relatively easy to identify and gives the operator control of which data should be removed. Leica Cyclone 8.1 software was used for the cleaning of the data.

The cleaned point cloud data was exported as an Ascii text file to ArcGIS software for further analysis. A total of 815393 point cloud was exported. ArcGIS 10.2.2 software package was used to generate the digital terrain model from the point clouds using the inverse distance weighted (IDW) interpolator.

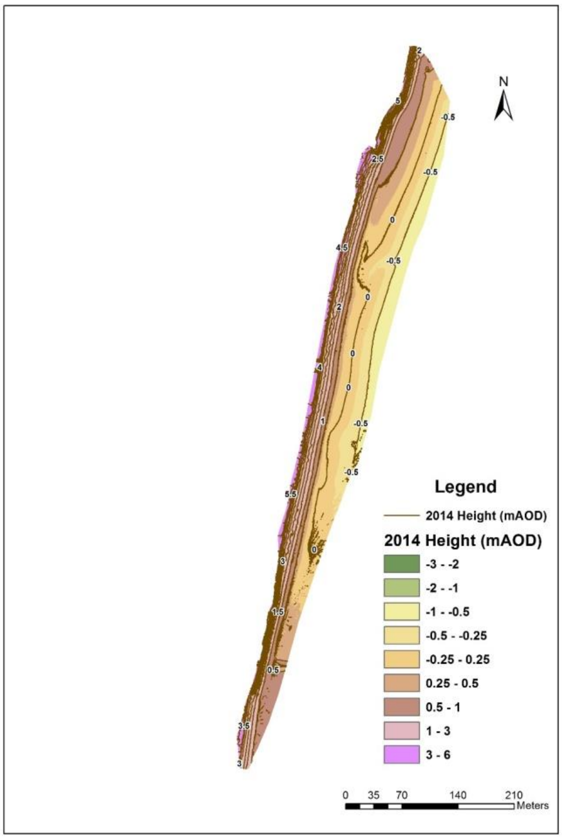


**Figure 12.** DTM from TLS point cloud data (2014)

## 1.5 Change Analysis/Modelling

For the change analysis the two DTM derived from the key methods described above were used to measure the coastal change over the period under review.

The Spatial Analyst and Geostatistical Analyst tools in ArcGIS were used to perform the change analysis. A mask was created to confine the processing extent to only areas with valid data between both surfaces created (Figure 3.8). Two key analysis and modelling were performed namely: height and volumetric change analysis/modelling.

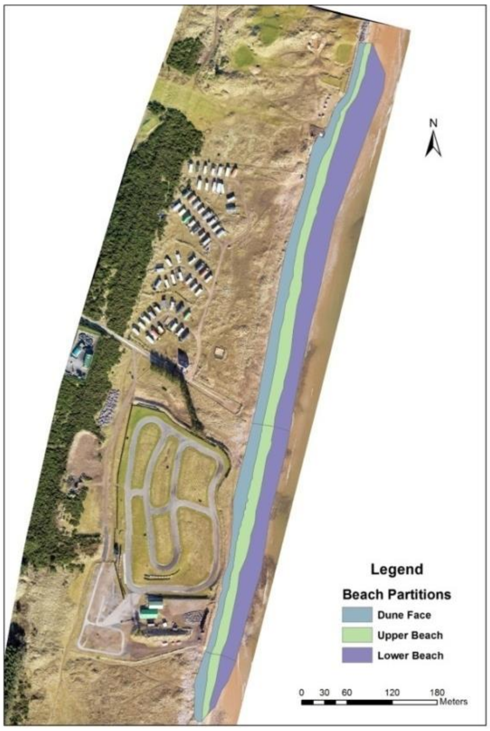


**Figure 13.** Partition of the beach into various constituent parts (dune face, upper beach and lower beach)

### 1.5.1 Height Change

Height change analysis involves the comparison of a before and after surface together so as to obtain a possible change in the elevation within the extent of the datasets. In this case corresponding cell values between both datasets are subtracted to determine the difference and this is later output as a difference surface representing areas where there has been a gain or loss in height.

### 1.5.2 Volumetric Analysis

Volumetric analysis quantifies the gains and losses in sediments between different time periods or raster surfaces. This task is performed by ArcGIS using the Cut/Fill function from two input surfaces. It measures the sediment change between a before and after surface. This is implemented by subtracting a before surface from as after surface which is the vice versa in height change.

According to the works of Zhang et al. (2005) the cut in the volume computation signifies areas with sediments between the horizontal zero plane and the positive surface directly above the zero plane while the “fill” are areas with sediments directly below the horizontal zero plane and negative surface of the grid surfaces used. The formula used to computes the cut and fill volume is presented below in equation 1&2 respectively.

Volume calculations in ArcGIS for “cut” areas are:

$$v_c = \sum_{\mathbf{i=1}}^{\mathbf{Np}} \mathbf{l^2 h_i} (1)$$

Where $\mathbf{v_c}$ is the volumes of the cut, $\mathbf{l}$ is the cell size, and $\mathbf{h_i}$ is the surface height of the ithcell while $\mathbf{N_p}$ is the number of cells with positive heights.

The volume of the fill ($v_f$) areas are calculated thus:

$$v_f = \sum_{\mathbf{i=1}}^{\mathbf{Nn}} \mathbf{l^2 h_i} \qquad (2)$$

Where $\mathbf{N_n}$ is the number of the cells with negative heights.

## III. RESULT AND DISCUSSION

The integration of both methods gave rise to the following 2D and 3D models of the study area. The changes were very distinct from the models and they are well marked.
The height change and volumetric models executed within GIS environment are presented below.

### 3.1 Height Change Models

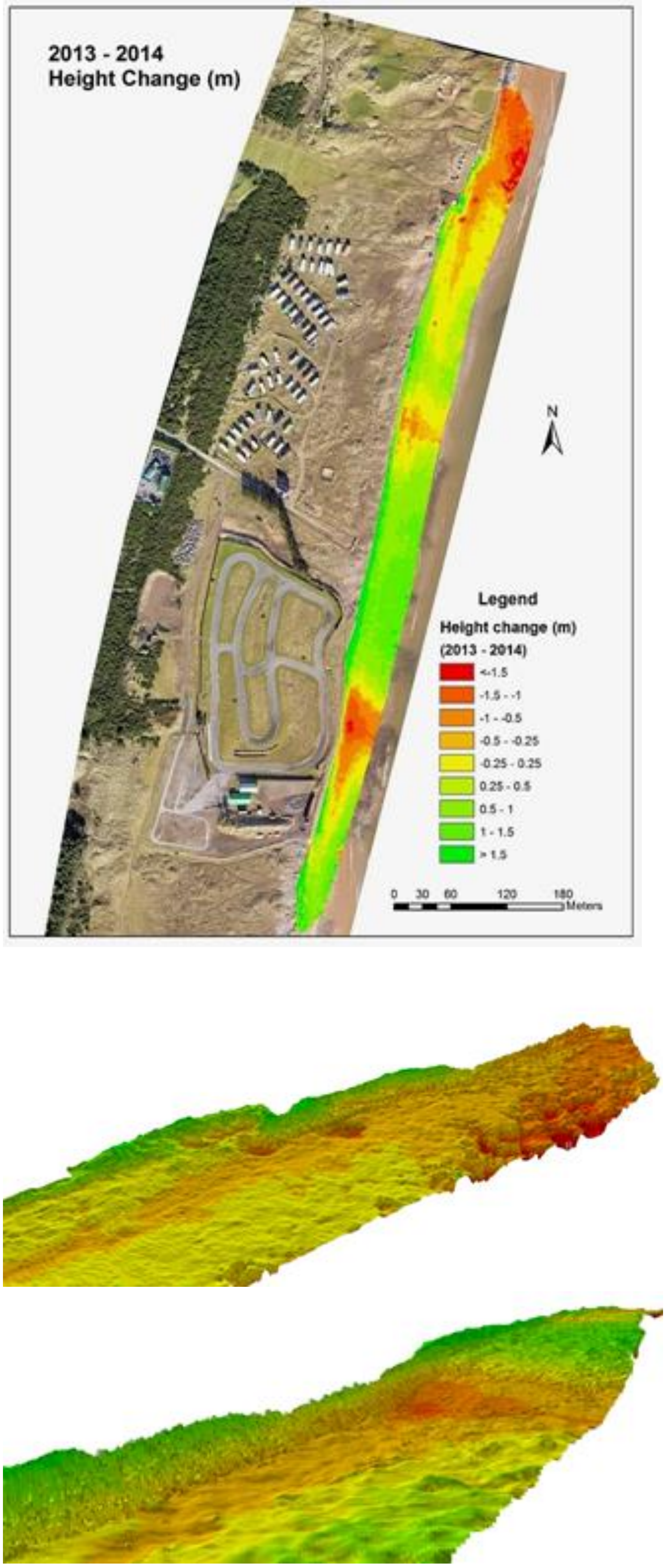


**Figure 16.** 2D and 3D models of height change at Golspie Beach showing the rate of height change within 2013 – 2014 time periods

A critical examination of the result from the height change models shows a wide spread of change in height at different sections of the beach. The southern end of the golf course witnessed most of the changes in height with substantial height loss of about 0.5m to 1.5m as represented with bold colours of red, orange while the areas with lesser loss are represented with lighter sheds of orange colours. Areas with greater gains in height or accretion are represented with bold greens with the lighter colours of green signifying milder gains.

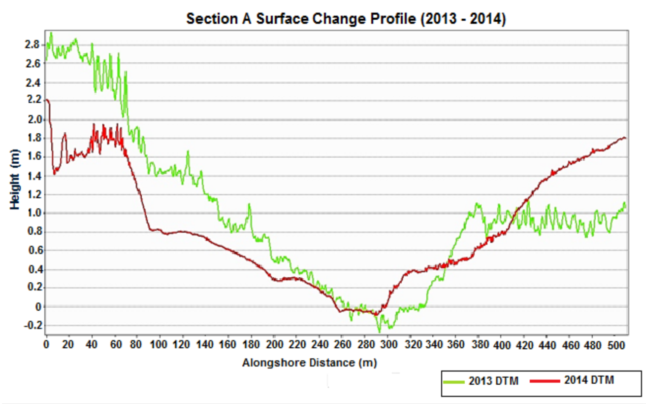


**Figure 17.** Alongshore surface profile change in height between 2013 - 2014 surfaces from the southern end of the golf course to the section of caravan frontage.

### 3.2 Volumetric Change Model

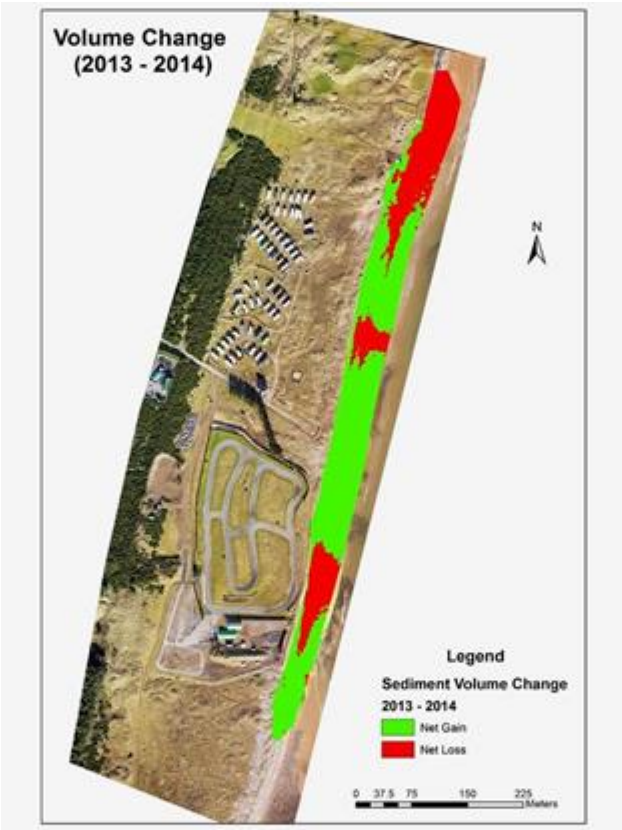


**Figure 18**. Volumetric change model showing areas of net loss and gain in sediment volume on the Golspie beach.

The areas colour-coded in green are places with gain in sediments with areas in red signalling loss in sediment. The southern end of the golf course and sections of the caravan park just adjacent to the golf course shows the greatest level of change, with the greatest loss in sediment recorded. The chart below shows the percentage change in sediment volume.

Figure 8 Graph showing the sediment change within the individual units of the beach represented in percentage (%). (2013-2014)

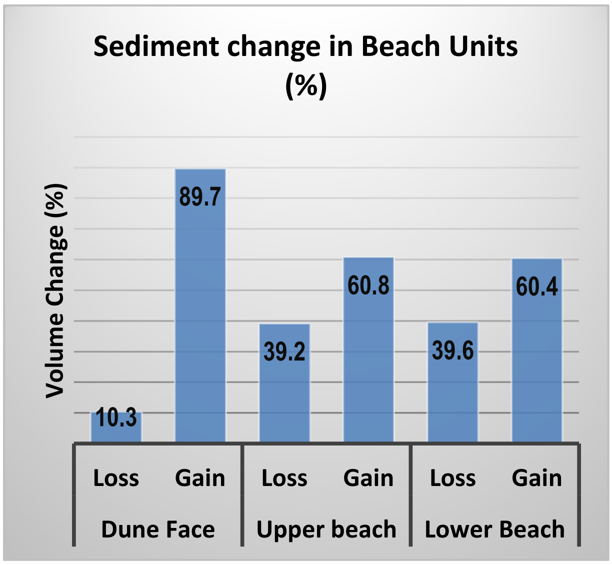


**Figure 5.** Graph showing the sediment change within the individual units of the beach represented in percentage (%). (2013-2014)

From the volumetric model the sediment budget was computed as shown in Table 2 below

Table 2 Sediment budget of the various units within the beach sections (2013 – 2014)

| Beach Section | Dune face | | Upper Beach | | Lower Beach | |
|---|---|---|---|---|---|---|
| | Loss ($m^3$) | Gain ($m^3$) | Loss ($m^3$) | Gain ($m^3$) | Loss($m^3$) | Gain($m^3$) |
| A | 777.3 | 4,301.8 | 1,356.7 | 1,729.7 | 4,383.4 | 3,382.2 |
| B | 249.0 | 3,424.3 | 1,394.3 | 1,916.8 | 828.3 | 3,845.6 |
| C | 1.5 | 1,227.0 | 5.3 | 630.5 | 11.3 | 743.5 |
| Total | 1,027.8 | 8,953.1 | 2,756.2 | 4,277.0 | 5,223.1 | 7,971.3 |
| Net change | | 7,925.3 | | 1,520.7 | | 2,748.2 |

## IV. CONCLUSION

This study has further validated the capabilities of terrestrial laser scanning and photogrammetry techniques for coastal mapping and landuse management. With these techniques the objectives of the study was actualised. The study revealed an on-going trend of beach change which was well marked by the results from this research. Although both DTMs had varied spatial resolutions, but re-sampling both to have similar grid cell size of 25 x 25cm makes them comparable and suitable for the analysis of change.

The findings from the result of the analysis showedthat the Golspie beach is highly unstable with interplay of erosional and accretional forces at work. The south end of the golf course experienced the greatest amount of changes in sediment volumes with a total loss and gain of approximately 6,517.3 m3 and 9,143.7m3 respectively. Generally, the study revealed more of gains in sediments than losses in the study area. The percentages of gain and loss are approximately 70% and 30% respectively. This is expected due to the increased intervention to protect the beach after the 2012 extreme storm that resulted in severe erosions on the beach. More materials were added to the beach during this period hence the increased gain in sediments. The study was successful using both DTMs from the two techniques.

Results such as this as obtained in this study, becomes an indispensable tool in the hands of coastal managers in providing effective and efficient landuse management of the coastal areas.

## V. ACKNOWLEDGMENT

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