Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Research Programme
- Short Call 2020, Final Report -

Lead Applicant Name	Colman Gallagher
Host Organisation name	University College Dublin
Project Title	Extraction of Historic DEMs and Orthophotos using Digital Photogrammetry and its Applications in Coastal Evolution Studies
Contract Number	2020-sc

This report covers the period 1st December 2020 to project end date 31st July 2022)

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2. (a) Project information:

Final project report (*max 2500 words, excluding figures and headings*):

Executive summary (lay abstract, approx. 250 words):
It has been documented that shoreline along South-eastern Irish coast is eroding at an average rate of 3-0.5 m/year (OPW, 2010; Mathew et al., 2018). While two dimensional changes in shoreline position, based on mapping of aerial photographs have been commonly used, determination of volumes of sediment transport and detailed sediment budgets have been rare because of the difficulty and/or expense of obtaining elevational changes over substantial distances alongshore. Repeated lidar and UAV surveys permit changes in topography to be determined (e.g., impact of storms) on beach dune systems; however, this still leaves the problem of how to obtain historical data at a similar spatial scale. This investigation explored the viability of generating high resolution historic DEMs and Orthophotos from 1955, 1971 and 2020 aerial photos by scanning contact prints and film negatives at 1200 DPI. Problems due to absence of reliable GCPs and camera calibration information's were overcome by using a combination of digital photogrammetry and structure from motion approaches. Liner, aerial, and volumetric changes in beach dune system were estimated over the past seven decades and was used to develop a conceptual model of the future evolution of the system. This proposal could be seen a pilot study for developing an integrated system of modelling shoreline change and sediment budgets that will integrate measurements in a range of spatial-temporal scales, which can be used for the entire Irish coastline.

(i) Results, scientific/engineering targets reached beyond the state of the art and conclusions

Recent advances in global positioning systems (GPS), multibeam echo sounder (MBES), light detection and ranging (lidar), unmanned aerial vehicle (UAV) sensor technologies paired with computational breakthroughs have paved the way for collection and processing of highly accurate and spatially as well as spectrally dense data of the highly dynamic coastal environment. The collection and analysis of such a unique data set can provide a myriad of opportunities for advancing both our understanding of collective alongshore and cross-shore sediment transport by waves, as well as aeolian sediment transport and coastal dune development (Davidson-Arnott, 2005; Mathew et al, 2010; Lynch et al., 2013; Delgado-Fernandez et al., 2015; Kandrot et al., 2016).

This, however, still leaves the problem of how to obtain historical data at a similar spatial scale. Advances in digital photogrammetry offers a relatively low-cost solution to this problem and the potential for construction of DEMs at a resolution similar to that of lidar (Mathew et al., 2010; Paine et al., 2012; Ollerhead, 2013; Mathew et al., 2019; Jaramillo et al., 2020). Good quality aerial photography coverage going back 75 years or more offers the potential to document this historical evolution of coastal beach and dune/cliff system at temporal scale that is useful for planning and policy decisions in coastal environment.

This investigation tested the feasibility of generating high resolution DEMs and orthophotos from historic aerial photos by scanning film negatives/contact prints and then processed it using Photogrammetry software such as PCI Geomatic and Agisoft Metashape in a desktop environment. Based on our investigation, this approach has the potential to document historical changes in the shoreline and beach dune sediment volumes at a scale that is useful for integrated costal management in all areas where shoreline management is required.

(ii) Implementation (milestones, deliverables, project management)

Task 1: Compile available historical aerial film negatives, scanning, pre-processing
In this investigation archived film negatives/contact prints of historic aerial photos collected in 1950 by Air Cops was gathered from the military archive office In Dublin. In addition, film negatives/contact prints of 1971 aerial images were collected from OSi office. Initially, remote sensing division at OSi agreed in principle to give access to the film negative repository, however, due to lack of stuff with expertise in photogrammetry and their internal policies restricted us from getting full access of the film negatives. However, after signing an academic research license agreement three stereo pairs were shared which covers areas to the east of New Ross along N15 highways. These film negatives will be scanned at a high-resolution of 1200 DPI and processed them in a desktop environment using PCI Geomatic and Agisoft Metashape photogrammetry software.

Task 2: To generate historic DEMs and Orthophotos using historic film negatives and contact prints
Ten to 15 stereo pairs of film negatives of historic aerial photographs taken in 1952, 1971, and 2020 UAV aerial images were used to quantify decadal scale volumetric changes in beach dune sediment budget. Firstly, film negatives of aerial photographs taken by The Irish Air Corps in 1952 and by GSI in1972 were digitally scanned at an optical resolution of 1200 DPI using a large format Drum scanner. Scanned images will be saved in Geo-Tiff format. Subsequently,

orthorectification and DEM extraction process will be carried out using PCI Geomatic Ortho Engine Photogrammetry software. Different processes involved in orthorectification, and DEM extraction is shown in **Figure 1**.

As the landscape changed substantially over the past seven decades, extensive field survey was conducted to collect accurate XYZ coordinates of potential ground control points (GCPs). Due Covid-19 related travel restrictions, this stage was the most time-consuming part as we must have to identify the potential GCPs first which then can be used for the internal and external orientation of stereo pairs. Orthorectification and DEM extraction of the 1971 was attempted first using ground control points (GCPs) that are visible on latest orthophotos (e.g. 1995) followed 1971 and 1955. As most of the identifiable features on the landscape such as road intersections, trails, monuments, and cultural features were missing on historic aerial photographs, finding accurate GCPs was one of the tedious tasks. To some extent these problems were overcome by using 1995 as a reference for 1971 and 1955. This means that additional GCPs from orthorectified 1995 images could be used to supplement the orthorectification of the 1971 and 1955 photographs respectively.
As shown in Figure 1, photogrammetry workflow can be divided into three stages, namely, data preparation, data extraction and data correction. During data preparation stage (see Figure 1), internal orientation parameters such as flying height, focal length, distance from the principal point to edges will be optimized for the entire model. Then external orientation will be attempted using GCPs to link the ground coordinates to image coordinates with an acceptable RMS error. During data extraction stage (see Figure 1), we ran the entire bundle-bloc adjustment (method to simultaneously estimate the internal and external camera parameters and the 3D coordinates of the scene points in a statistically optimal manner) to extract DEMs and orthophotos from individual stereo pairs and it was then merged into seamless one mosaic image. In the final stage, data correction was attempted on extracted DEMs and orthophotos by comparing it with original stereo pairs from which these products are derived. Final orthophoto mosaic (**Figure 2)** and digital surface model (DSM) from digital photogrammetry can be found in **Figure 3**.

Task 3: To evaluate the accuracy and precision of DEMs and Orthophotos generated from historic aerial images and to determine change in sediment volume
Accuracy of the DEMs and Orthophotos generated using photogrammetry workflow was verified using a combination of qualitative and quantitative approaches. Ideally, accuracy assessment should be done by comparing DEMs with a contemporary independent data source with a higher order of accuracy. We have consulted OSi and Wexford County council regarding the availability of GCP information which was collected as part of the historic aerial photographic mission. Also, note that Photogrammetric workflow used for processing historic aerial images are the same as modern UAV images. Therefore, it is reasonable to assume that if the modern UAV based DEMs are accurate enough, we can expect the same level of accuracy from historic aerial images apart from limitations imposed by GCPs and the quality of photo images.

Qualitative testing was done by interactively editing points that do not appear to lie on the surface of a stereo pair. Initially, this can be done by overlaying the DEM on a stereo model of the surface using stereovision option within the PCI Geomatica OrthoEngine Photogrammetry software. It allowed us to manually edit the failed cells with a range of options such as interpolation of the failed cells with successful neighbouring pixels, masking of failed areas, and a range of filtering techniques.

For quantitative testing, independent data sources with a high order of accuracy (e.g., RTK GNSS system) was used to check the accuracy of extracted DEM. In this investigation, the accuracy of the 1995 DEM was tested by comparing it with a landmarks/monuments/road intersection that are still unchanged. The vector sampling function in PCI Geomatica OrthoEngine module was used to extract pixel elevation values from the DEMs of each year. Output from this tool was a text file with XYZ co-ordinates of the vector layer and the Z co-ordinate of the respective raster DEM layer beneath it. These text files were then imported to Microsoft Excel and summary statistics was calculated for selected profiles and GCPs along the Study area. Figure 6 show the elevation change dynamics along the transects Profile_N, Profile_M and Profile_S. From these scatter plots over the last 7 decades beach dune system has lost considerable amount sand to the nearshore system. Table 1 also summarises the statistics of 2020 DSM with the RTK GNSS data. Collected along these profiles.

Moreover, within the PCI Geomatica Ortho Engine and Agisoft Metashape software, there was an option for generating additional image channels that give the correlation score for each DEM pixel at which GCPs were collected. This RMS error was also used to identify pixels with poor or failed correlations to the ground, which gave a truer impression of the success of the operation.

Task 4: Estimation of decadal scale beach dune sediment volume and Sediment budget

To assess the spatial and temporal pattern of the evolution of the Study area, edited DEMs of 1953, 1971 and 2020 was analysed visually by using three-dimensional models of overlaid surfaces. Based on the historic shoreline change rates (Figure 5), the Study area will be divided into three reaches namely highly eroding northern part (vicinity of BallinEsker area), stable middle section (vicinity of Raven north and Curracloe area), moderately eroding southern (vicinity of Ravens Point). The ArcGIS extension tool Spatial Analyst and 3D analyst were used to clip out the DEM portions, which cover common areas in the above coastal reaches.

The basic method used for identifying topographic change between DEMs was differentiating the Z coordinate values on each grid cell of a DEM pair. In this investigation, the ArcGIS extension tools, 3D analyst and Spatial Analyst were used to compute the volumetric and elevation change value at each cell location with a reference plane height of zero. Furthermore, a positive, negative or zero volumetric value at a grid was considered as the amount of deposition, erosion, or no change respectively. These results were exported to an Excel spreadsheet and volume change and change-rate per unit length were calculated for the periods of measurement (see Table 2). Finally, line graphs were used to show the total volume and the volumetric changes and maps of elevation change was used to visualize the spatial and temporal pattern of topographic changes over the periods of measurement.

Attempts were also made to quantify the evolution of coastal reaches separately, by analysing the topographic and the volumetric changes associated with selected features and by extracting profiles across areas of interest (See Figure 4 and Table 1). Procedures for the profile extraction, volume calculation, and the visualization techniques was the same as explained above.

In this investigation, conceptual models on future evolution of beach dune system were by quantifying linear changes in shoreline change rates, areal changes in morphological units were used to estimate average sediment transport rate (see Table 2). This had permitted us to have a better understanding of inputs, throughflows and deposition of sediment during the periods of measurement.

As shown in table 1, the volume of sediment lost or gained during the period 1955-1971 for the whole reach will be determined. Later, volumetric change-rates per unit length was calculated by dividing the total volume change by the number of years and by the length of shoreline. Finally, a sediment-budget approach was used to summarize input, through-flow, and output, as well as net deposition, during periods of measurement for the study area as a whole and for individual areas of interest along/across coastal reaches

(iii) Outputs to date

As evident in Figures 1, 3, 4 the location of the Study was in County Wexford along Raven beach and forest (to the south) and Curracloe and Ballinesker beach to the northern.

(iv) Impact

- Relevance/application to GSI programmes, where applicable

One of the most important impacts of this project would be to develop an approach and methodology that can be used to generate high resolution DEMs and orthophotos from film negatives. The success of this approach will have applications beyond the domain area, especially where people want to find subtle signals in topography, ones that can be obliterated by modern agricultural methods and urbanization.

Results from this investigation could be particularly useful to GSI in Coastal and Marine unit in GSI and OPW coastal division shoreline erosion/accretion investigations, pre-and post-storm surveys, oil spill response, habitat mapping, near-shore beach-dune, and wetland restoration studies along the study area. Decadal change volumetric changes in beach dune sediment budget on a decadal scale, along the Irish coast and, eventually elsewhere, are potentially of great value for emergency preparedness (identifying highly vulnerable areas for populations and infrastructure), insurance risk assessments, urban planning, coastal habitat management, beach renourishment and inlet dredging strategies, and setback lines and building standards for coastal structures.

- Other impacts

We intend the proposed investigation as a pilot study to take a leadership role in study of storm surge impacts and geo-hazards on coastal communities by fostering early career scientists (post-doctoral and graduate/undergraduate), and through the extensive outreach apparatus of the UCD EI (non-technical publications, websites, media relations). The UCD EI is a leader in the development of programs to train secondary school teachers, and students, and this investigation will be used as a foundation for developing partnership with coastal communities through inviting participation in field, laboratory, and classroom study.

A central commitment of the proposal will be to deliver public dissemination of outputs to better equip our society to adapt to geo-hazards, climate change, population growth, economic development, and resource constraints. New tools and prototypes developed as part of this investigation will be added to new and existing web resources at GSI and UCD, including downloadable reports. The project can increase societal resilience by learning how best to use the coastal and marine datasets to inform better coastal environmental policymaking and planning. Consequently, the project can contribute to the development of the scientific and human resource capacity needed for sustainable use of coastal resources.

The outcomes of PI's research are already made available freely to the public and they will assist students working on similar coastal projects and computational assignments. PI's will incorporate the research findings of this investigation into their research and undergraduate modules. These modules reach approximately 250 students per year. These activities will encourage cross pollination of students interested in geosciences, coastal resources management, and societal impact of climate change.

Publications:

Initial results from this investigation were used in a poster for the IGRM annual conference. Currently working on a technical communication paper on approaches and problems of extracting DEM and orthophotos using historic aerial images.

Mathew, S., Gallagher, C., Pellicer, X., Monteys, X. 2022. Geospatial spatial analysis of beach dune evolution from Blackwater to Wexford Bay, Co. Wexford using remote sensing approaches. IGRM, February 25th, 2022.

3. Supplemental information/datasets

Processed data used in this investigation can be downloaded from the following link:

https://1drv.ms/u/s!Al_Gvoil_AjUieUfQzBBExErxzu-og?e=DtVrfT

List of figures and tables:

List of Tables:

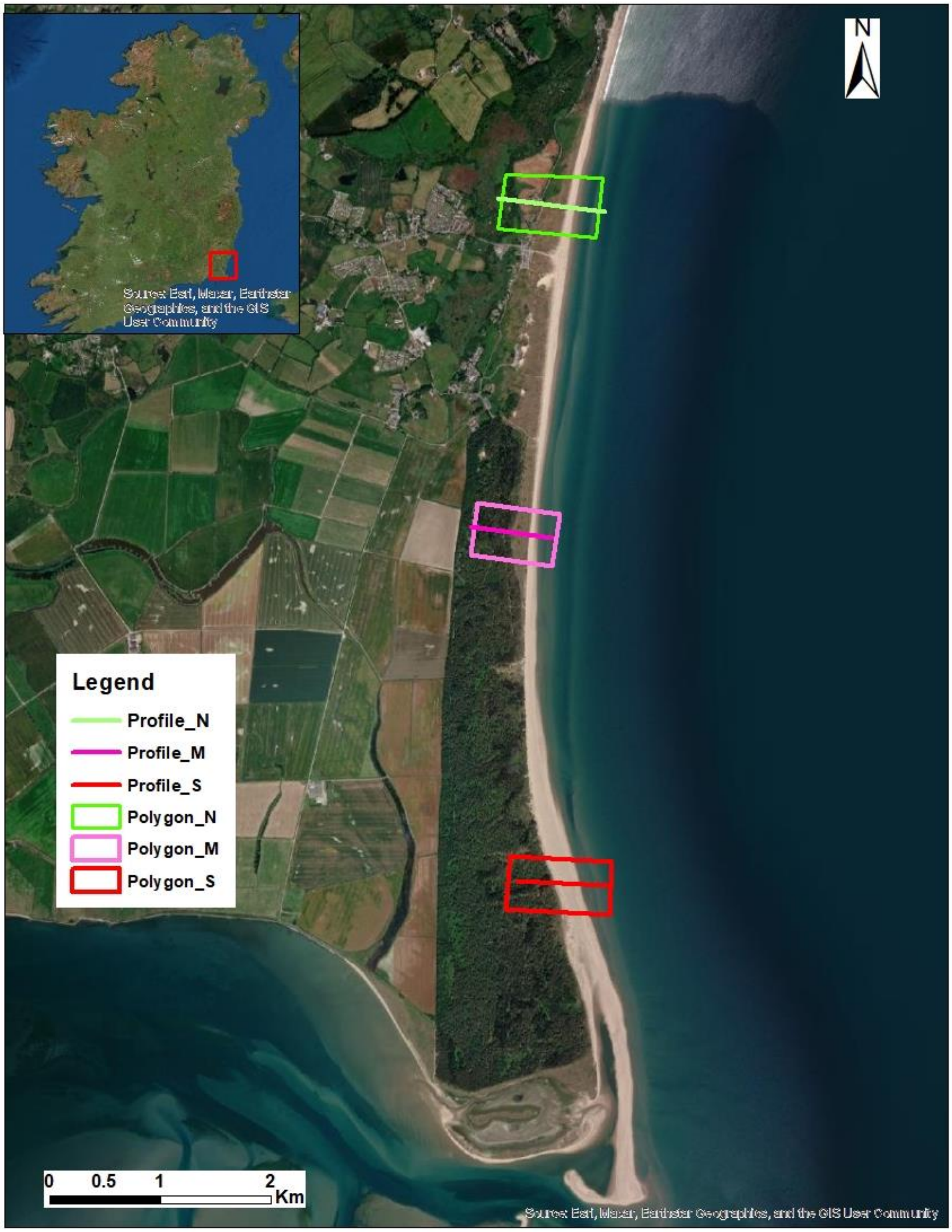


Figure 1: Map showing the spatial extent of Study area and an overlay of line and polygon features test the profile dynamics and volumetric changes

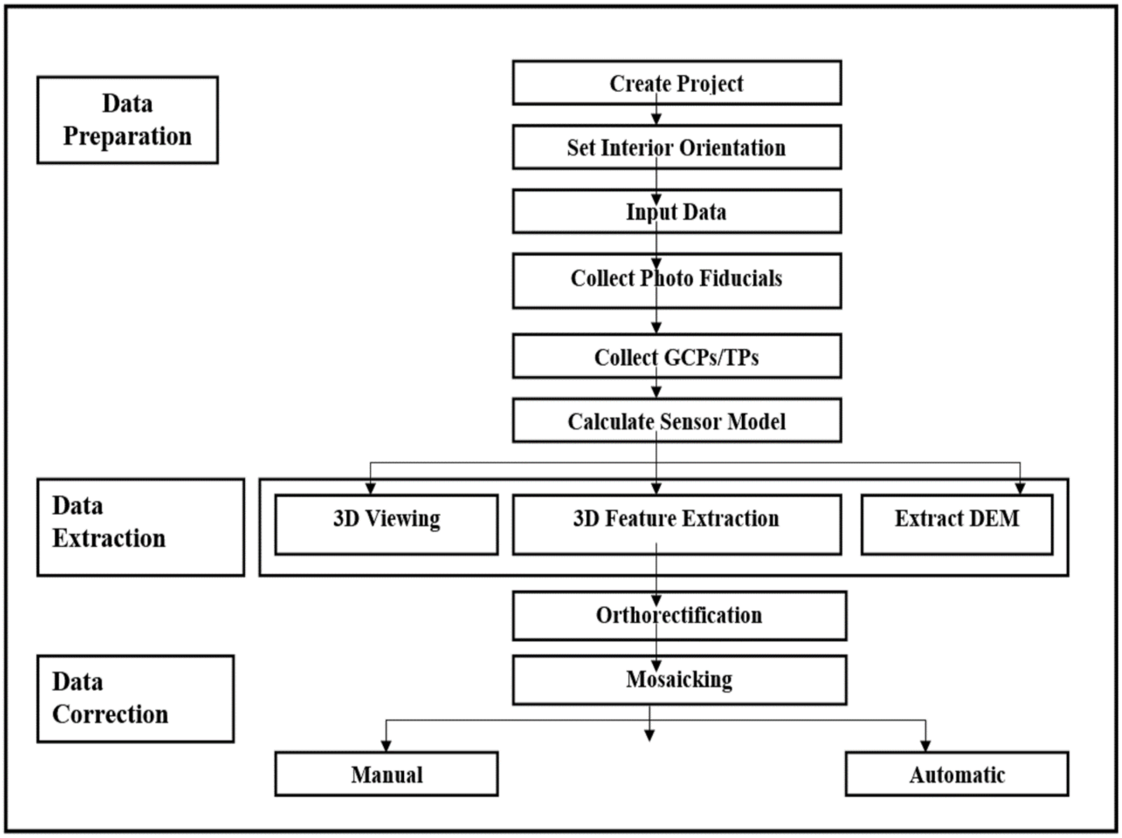


Figure 2: Flow chart showing the digital photogrammetry workflow for the generation of orthophotos, DSMs and orthophoto mosaic using PCI Geomatica OrthoEngine Module

Figure 3: Map showing the orthophoto photo mosaic of 2020 (UAV) and 1971 and 1955 historic aerial images. Line and polygon features are used as an overlay to show the profile dynamic and volumetric changes across the AOIs.

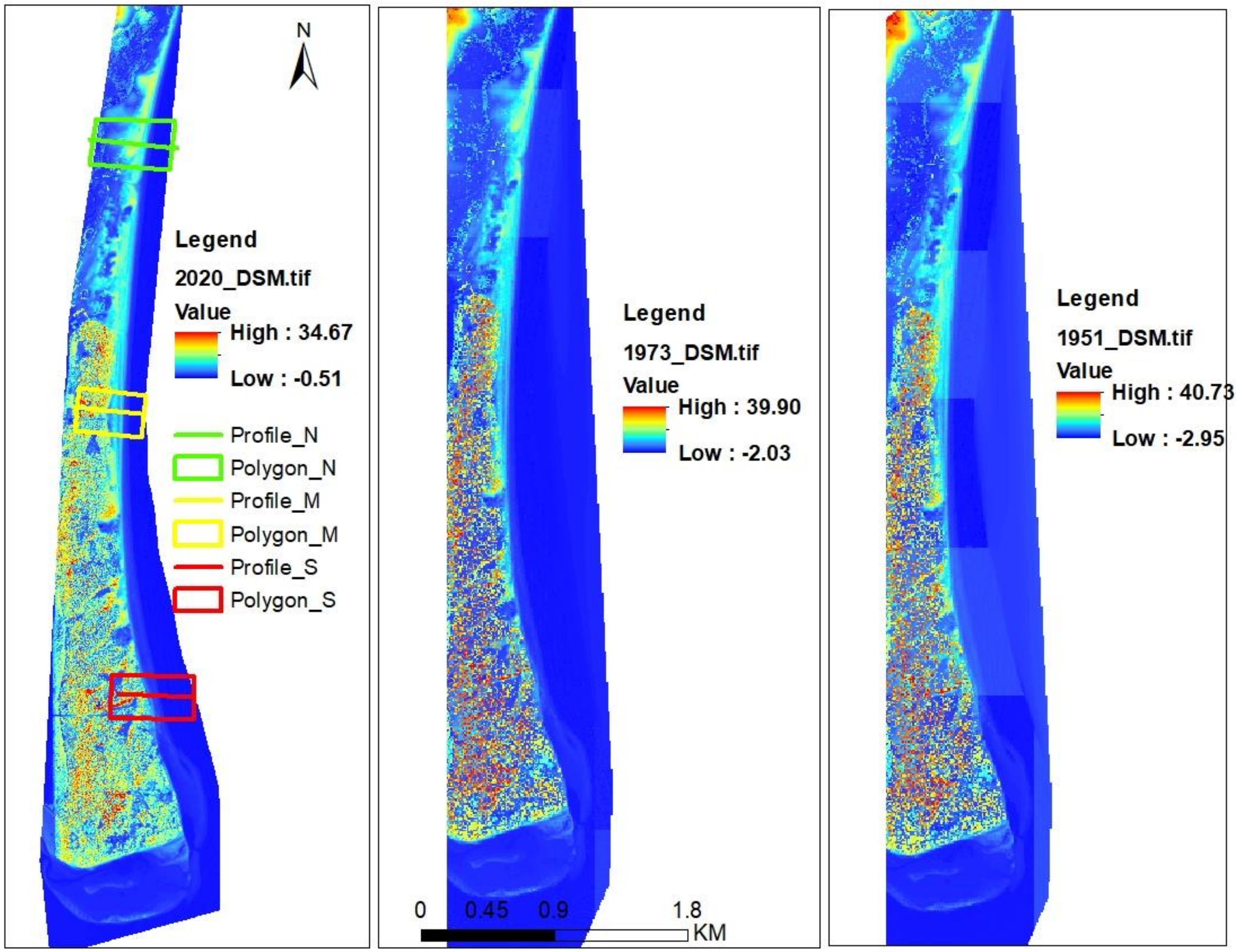


Figure 4: Map showing the DSM of 2020 (UAV), and 1971 and 1955 historic aerial images. Line and polygon features are used as an overlay to show the profile dynamic and volumetric changes across the AOIs.

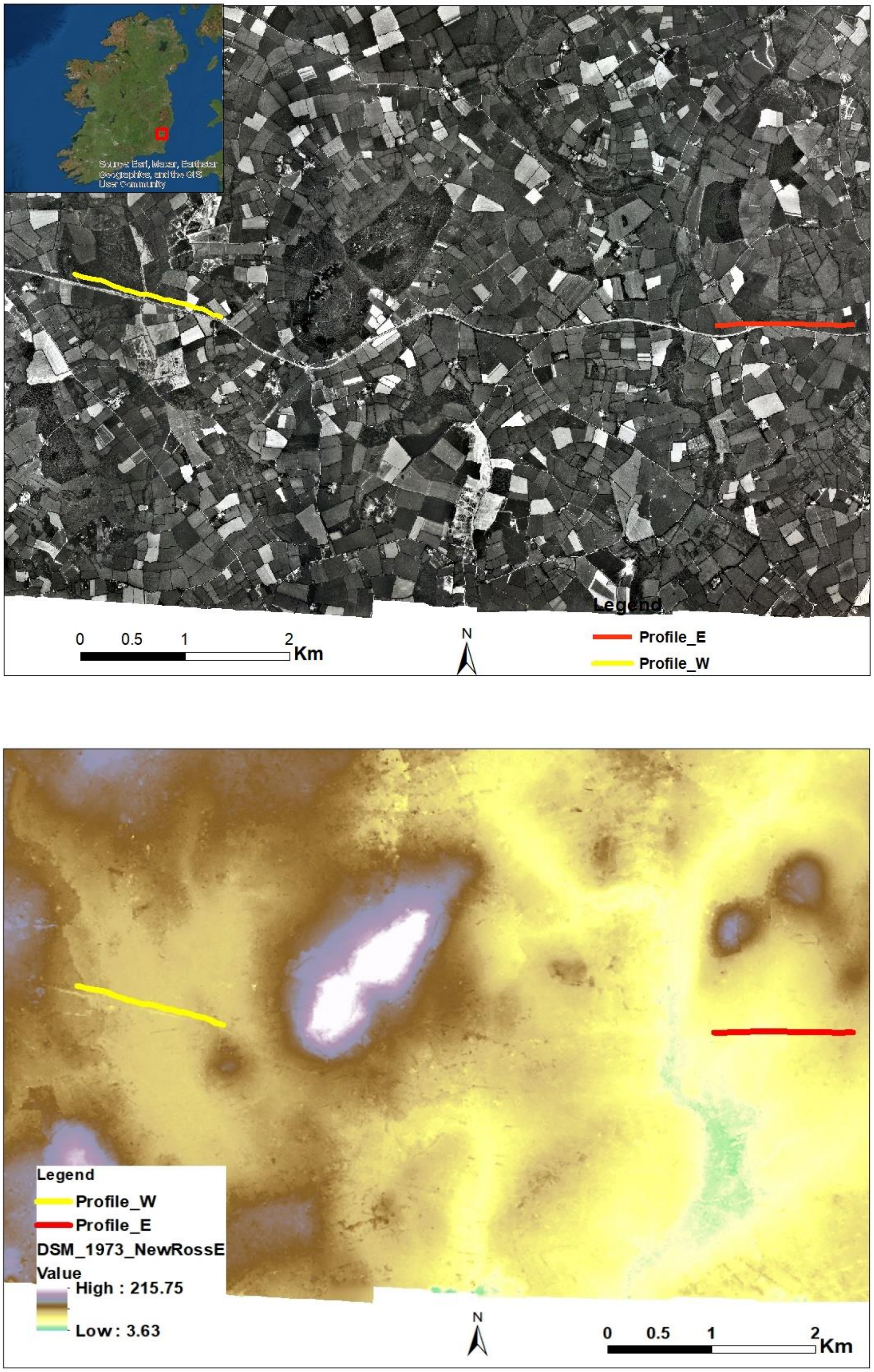


Figure 5: Map showing the orthophoto mosaic and DSM generated using scanned film negatives at 1200 DPI. Two-line features (profile W and Profile E) are used to evaluate the elevation changes in comparison to real time kinematic profiles.

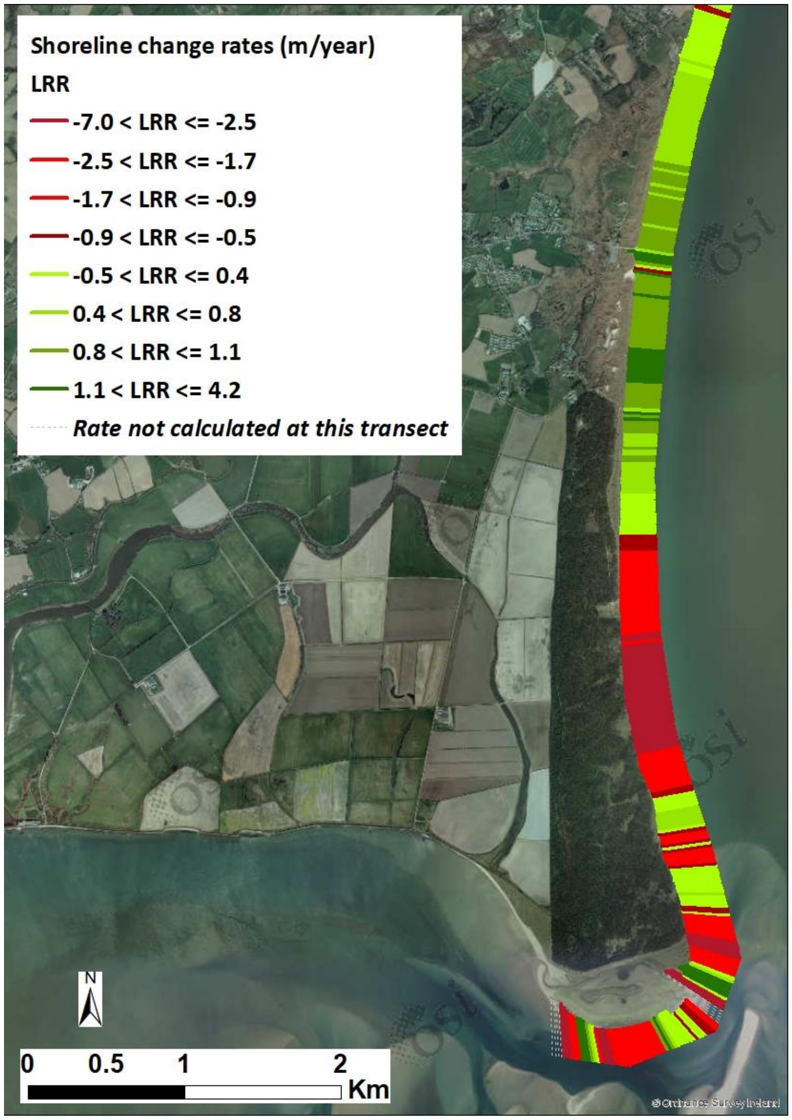
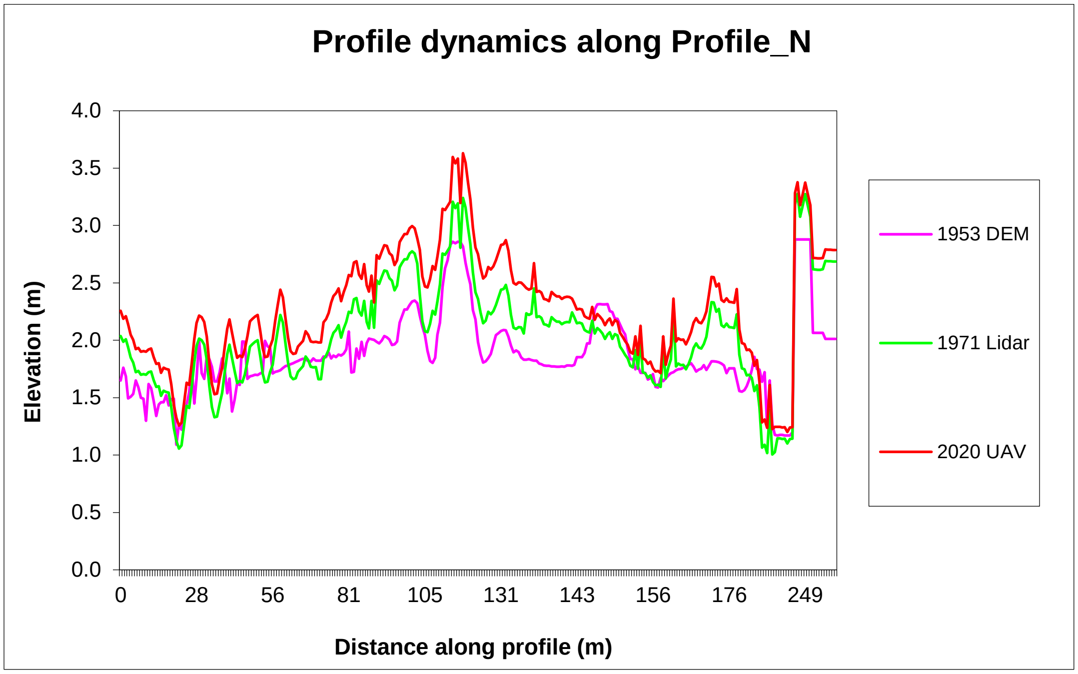


Figure 6: Long term shoreline change rates along the Study estimated using digital shoreline analysis system (DSAS) using 1953, 1971, 1995, 2005, 2020 aerial images.



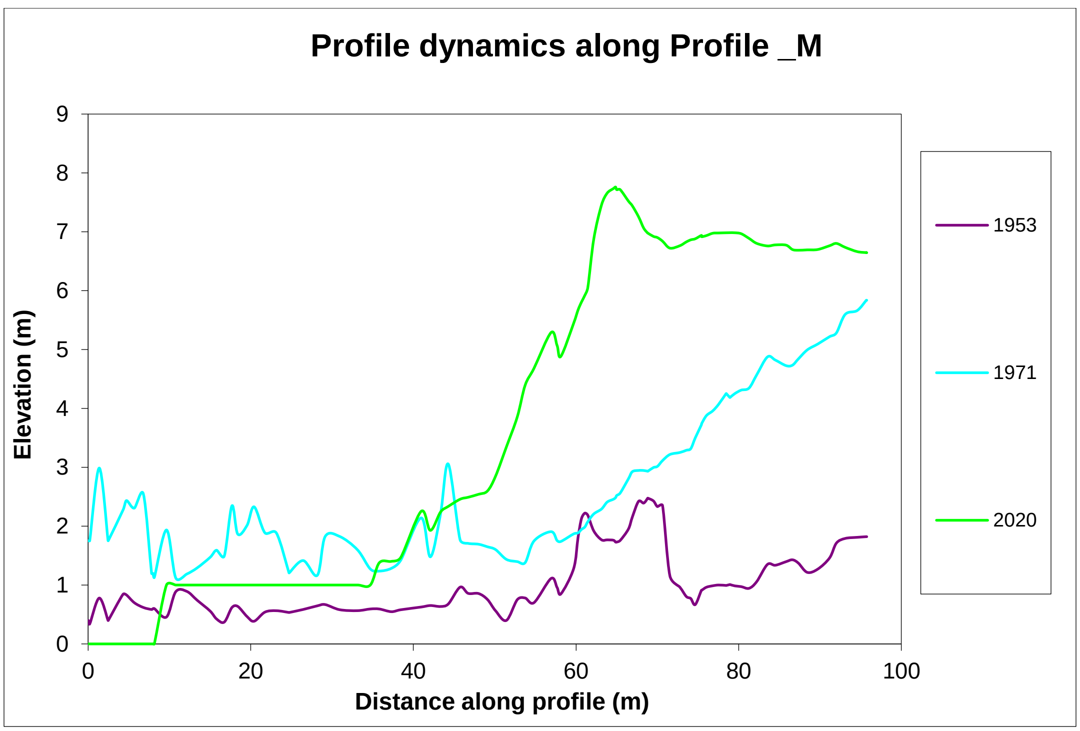


Figure 7: a) Elevation change graph along Profile_N (top); b) Elevation change along Profile_M (bottom) based on 1953, 1971 and 2020 DSM. Location of these profile is shown as an overlay on Figure and Figure 3.

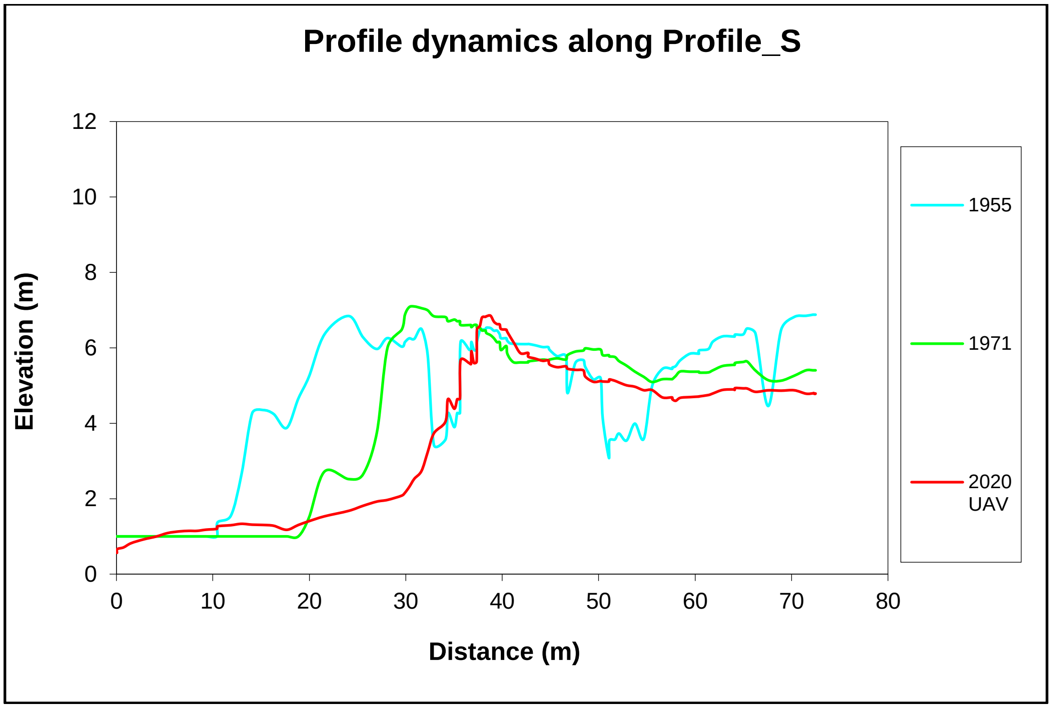


Figure 7 cont.: c) Elevation change along “Profile_S” in 1955, 1971 and 2020.

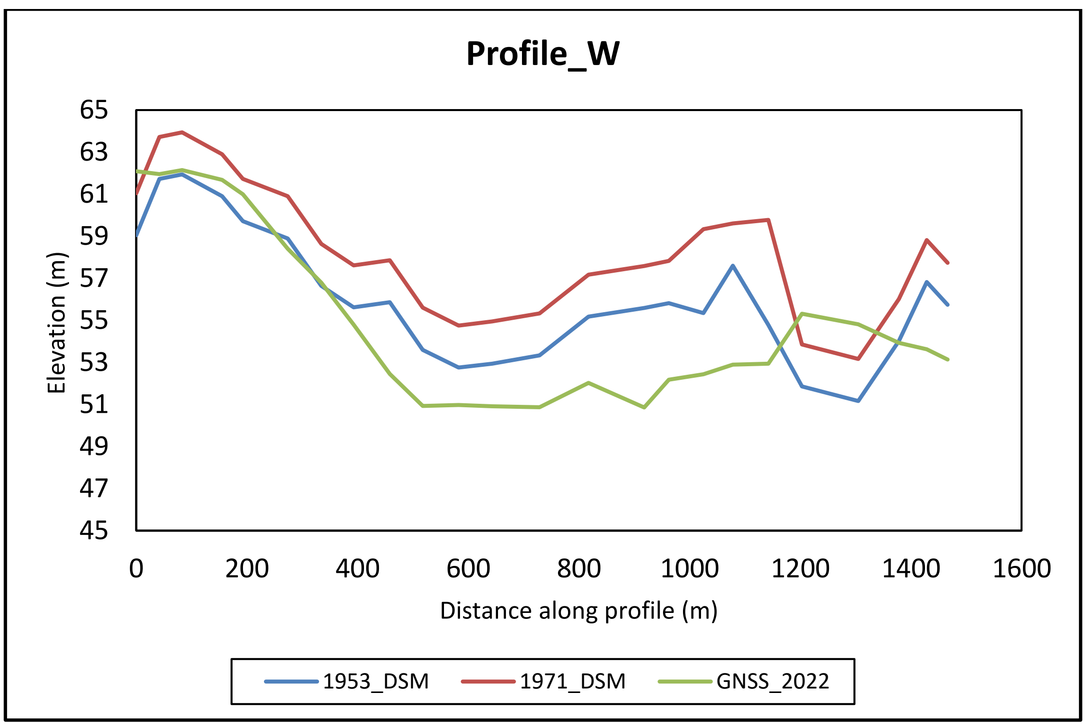


Figure 8: a) Graph showing elevation changes along Profile_W based on 1953, 1971DSM and 2022 GNSS profile. Location of the profile is overlaid on Figure 5.

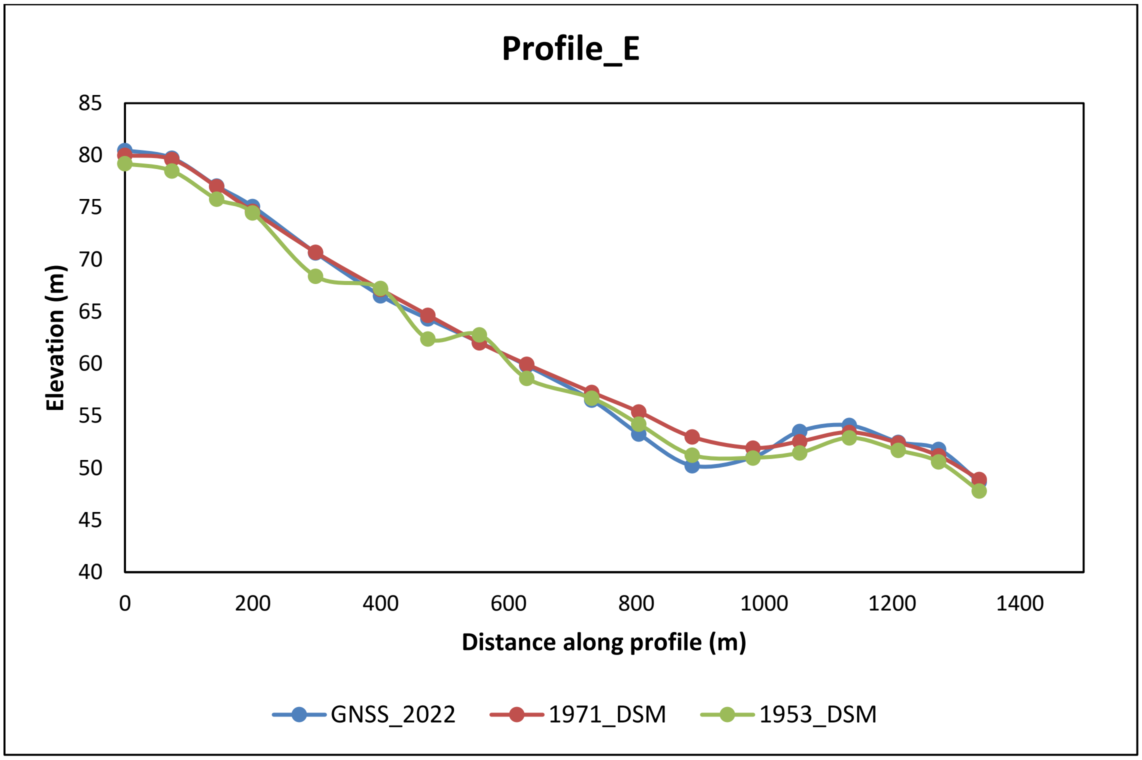


Figure 8 cont.: b) Elevation changes along Profile_E based on 1953, 1971 DSM and 2022 RTK GNSS survey. Location of the profile is overlaid on Figure 5.

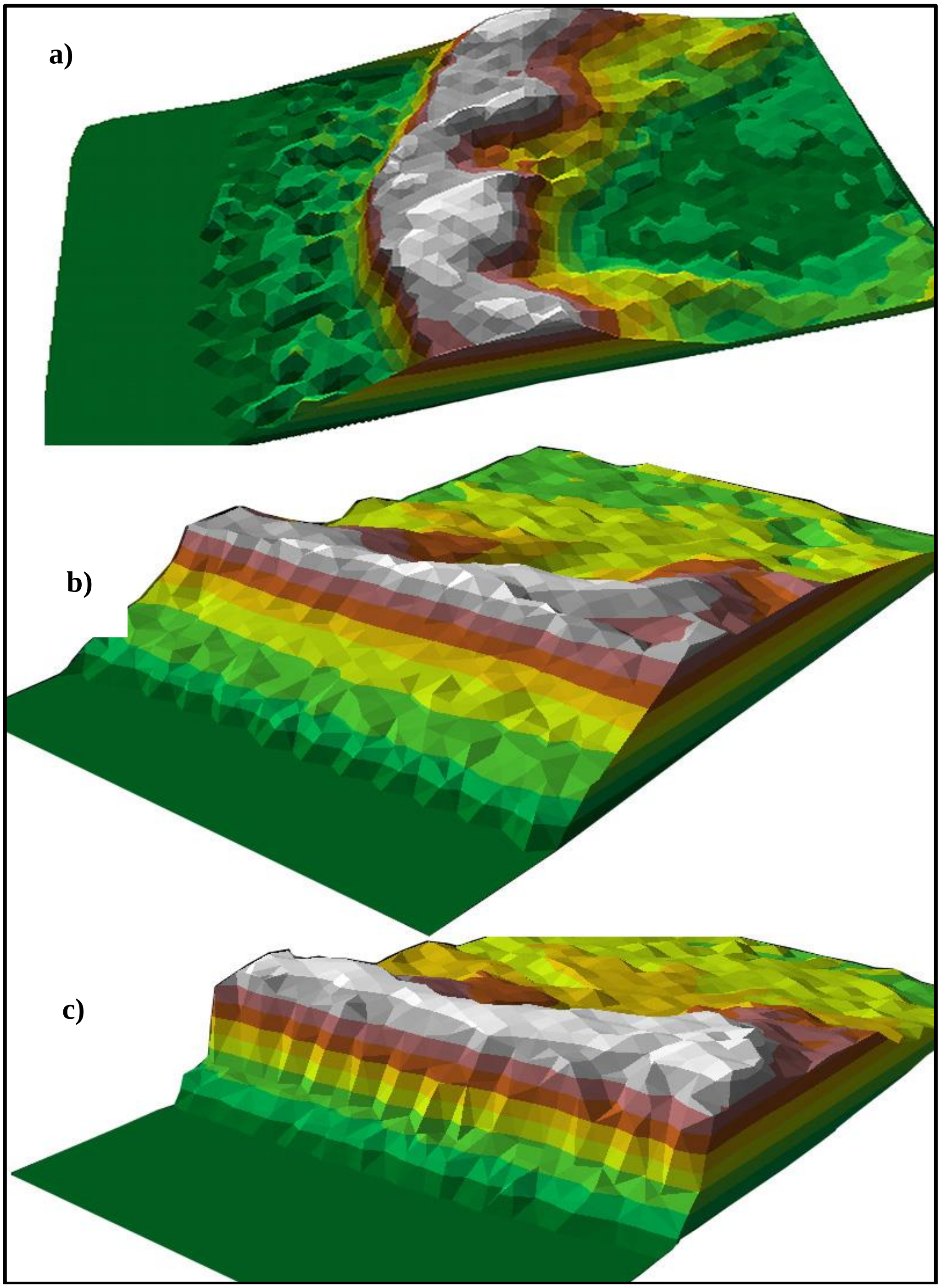


Figure 8: Conceptual model of beach dune system evolution along the area of interest a) Polygon_S (top), b) Polygon_M (middle), and c) Polygon_N (bottom) based on linear change in shoreline change rates, areal change in geomorphic units and volumetric change rates. Location of these polygons are shown in Figure 1 and 3.

Table 1: Accuracy assessment of selected features in 2020 DSM with RTK GNSS Survey

Feature	Periods of measurement	Mean Z difference (m)	Median (m)	SD	Maximum (m)	Minimum (m)	Range (m)	Count
Profile_N	2020-2022	0.87	0.76	0.05	1.00	-2.02	3.01	284
Profile_M	2020-2022	0.54	0.84	0.19	1.71	-1.22	2.93	284
Profile_S	2020-2022	0.52	0.79	0.38	1.73	-0.11	1.85	37
Profile_W	2020-2022	0.61	0.48	0.42	1.03	-1.79	2.82	37
Polygon_N	2020-2022	0.72	0.59	0.34	1.15	-0.72	1.87	47
Polygon_M	2020-2022	1.10	0.65	0.35	1.46	-2.24	3.70	47
Polygon_S	2020-2022	0.56	0.33	0.58	2.03	-1.45	3.48	34
Polygon_W	2020-2022	1.18	0.80	0.59	2.34	-1.45	3.78	34
Polygon_E	2020-2022	1.24	0.77	0.30	0.93	-0.42	1.35	31

Table 2: Overall volumetric change-rate per unit length during the periods of measurement

Year	Total volume (m^3)	Periods of measurement	Volume change (m^3)	Volume change-rate ($m^3m^{-1}a^{-1}$)
1955	4.69×10^6	1953-1971	2.18×10^6	30.21
1971	5.86×10^6	1971-1997	3.29×10^6	36.37
2020	7.16×10^6	1953-1997	4.47×10^6	23.29