Identification and forecasting of coastal erosion using aerial and UAV images

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ABSTRACT

This study seeks to establish a methodology in order to determine the rate of coastal erosion using temporal aerial and UAV images. Part of the methodology focuses on forecasting coastal erosion and mapping Posidonia oceanica. Initial results indicate that there may be a correlation between coastal erosion and other related dynamics, such as the presence of Posidonia oceanica. UAV images acquired using UAVS in the Spyros Beach area near Larnaca, Cyprus were compared with aerial photos provided by the Lands and Surveys Department of the Government of Cyprus in order to estimate coastal erosion. In this study, the results indicate that, instead of coastline erosion, the coastline is actually expanding at a constant rate over the forecasted period. The beach nourishment observed may be related to the reduction of Posidonia oceanica. This reduction of the Posidonia oceanica forms a natural breaker between the shoreline and the sea, leading to a reduction of wave energy which thereby results in an enhanced accumulation of sand at the beach.

Keywords: coastal erosion, UAV, Posidonia oceanica, survey, aerial images

1. INTRODUCTION

A coastline survey was conducted in May 2021 using a drone with a 20MP camera and the images produced were compared with aerial photos from 1993, 2008 and 2014 provided by the Lands and Surveys Department of the Government of Cyprus in order to estimate coastal erosion and map Posidonia oceanica. Posidonia oceanica, commonly known as Neptune grass or Mediterranean tapeweed, is a seagrass species that is endemic to the Mediterranean Sea. Posidonia oceanica has been called "the lungs of the Mediterranean" because it is one of the most important sources of oxygen provided to coastal waters.

In the study, an accurate survey with 36 ground control points (GCPs) were established in order to geo-reference the Unmanned Aerial Vehicle image and the aerial photos. The coastlines from the different images were calculated using the Excess Red Index and calculated the rate-of-change statistics of the shoreline positions. Also, the Posidonia oceanica was mapped using the Excess Green Index to quantify the reduction of the Posidonia oceanica. The results of the rate-of-change of the shoreline was compared with the reduction of the Posidonia oceanica, which indicated a correlation. This tool can be used as a method to calculate the rate of the shoreline change and identify any possible variables for such changes.

2. STUDY AND METHODOLOGY

The study area for the erosion investigation survey was the Spyros Beach coastline in Larnaca, which is located next to Larnaca International Airport. In order for the survey to be conducted, special permission needed to be granted by the Cyprus Aviation Authority, since the area is characterized as a controlled airspace due to its proximity to the Larnaca Airport. The documentation process included a survey of the area, beginning with the placement of 36 ground control points (GCPs) in different areas on Spyros Beach. The GCPs were distributed evenly around the site in order to geo-reference to create a centimeter accuracy ortho-image.

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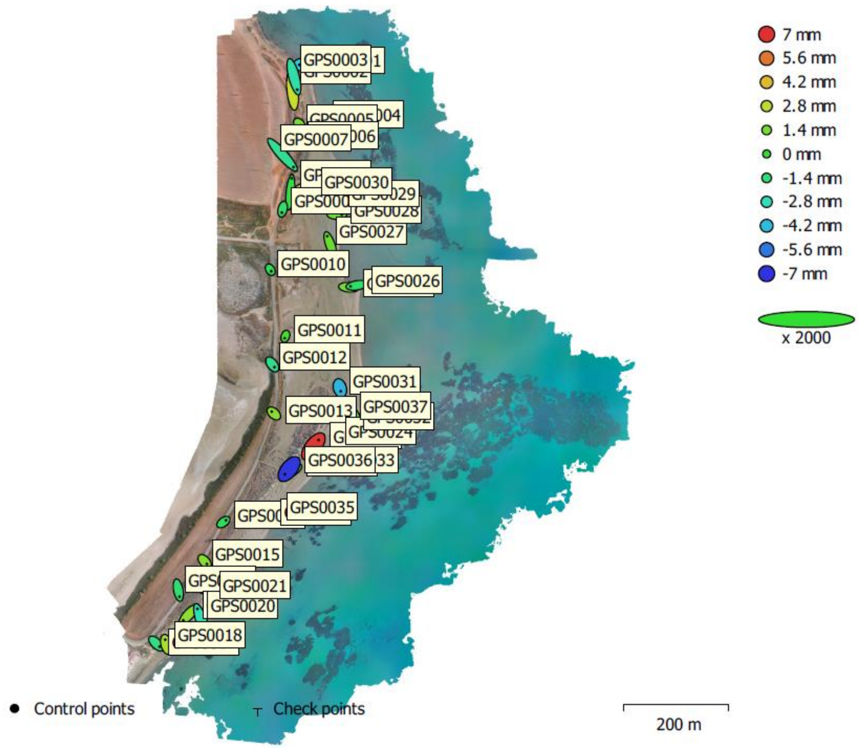

Figure 1 Ground Control Point locations and error estimates

An Unmanned Aerial Vehicle (UAV) with a 1-inch CMOS and 20MP camera was used to take images of the Spyros Beach Area. UAVs have been used in a broad range of ecological research projects, especially in marine environments [1]. The survey area coverage was approximately 1km^2. The UAV flew at an altitude of 120 meters and acquired 1,396 aerial images to be processed using Structure for Motion (SfM) photogrammetry method. The photogrammetric survey was conducted using aerial imagery, which was created from processing the 1,396 aerial images taken with the UAV into 3D points clouds, 3D surfaces and ortho-photos.

Figure 2 Ground control points (GCPs)

Research indicates that UAV images combined with SfM photogrammetry can deliver very high spatial resolution maps usable for identifying and characterizing sensitive coastal marine habitats [2]. The Structure from Motion (SfM) photogrammetry tool was used, which enables 3D reconstruction of the area of interest by generating good quality meshes from images in a semi-automatic way. The software analyses the dataset, detecting geometrical patterns in order to reconstruct the virtual positions of the cameras that were used in order to align the images, including building a sparse point cloud [3-5]. Structure for Motion (SfM) photogrammetry software was used to generate a point cloud of Spyros Beach from the aerial images using the GCPs to geo-reference the models resulting in an ortho-photo that provided an accurate documentation of the area (Figure 3). The ground control points were marked with water-soluble biodegradable spray paint around the area in order to get the accuracy of the images processed by the photogrammetry to a cm accuracy. The ground control points were distributed around the area of interest and geo-referenced with an RTK GPS connected with the Cyprus Lands and Surveys CyPOS reference system using the LTM projection system.

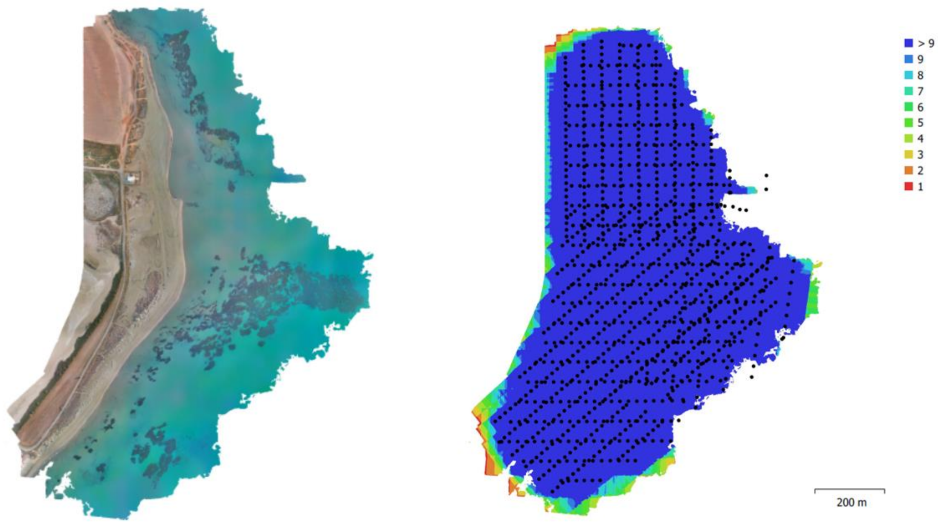

Figure 3 Left: Ortho-image from UAV images. Right: Camera locations and image overlap

The ortho-image had a total of 1.40 cm accuracy with ground resolution of 3.19 cm per pixel. The excellent accuracy was a result of the 36 GCPs that were distributed throughout the area of interest. A Digital Elevation Model was created in order to accurately calculate the shoreline of the coast (Figure 4).

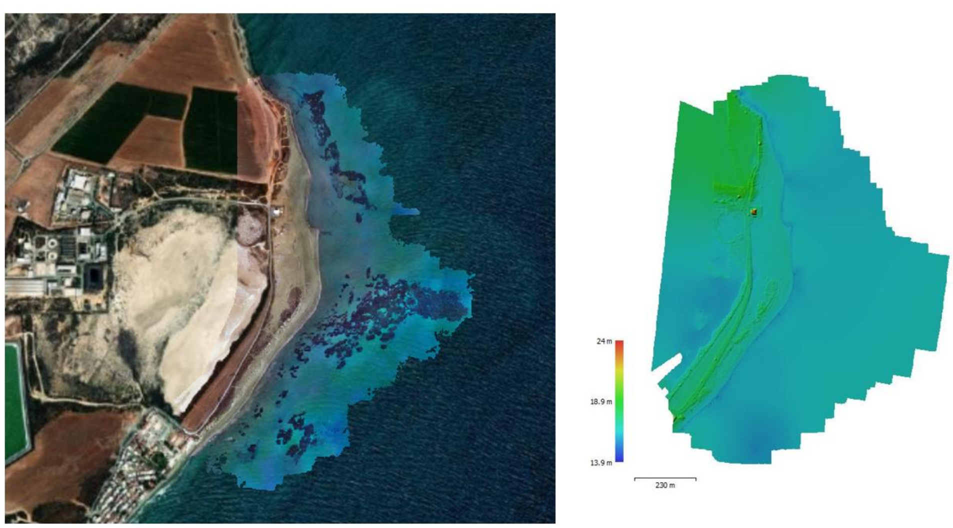

Figure 4 Ortho-photo overlay with satellite image and Digital Elevation Model of the area

In order to compare the coastlines over time, aerial images from 1993, 2008 and 2014 acquired from the Lands and Surveys Department of Cyprus and the UAV images that were acquired in May 2021 were geo-referenced and match using common features that did not change over time that were visible to all images. These features included the road north of the coastline, the corners of buildings and other stationary objects which have existed at the site since 1993 and have not changed or moved since then. The UAV image was used as a base reference since it was the only high-resolution image that was accurately geo-referenced using 36 GCPs. A second order polynomial transformation was used to geo-reference all aerial images with the UAV image. This method provided a precise geo-reference match for comparison of all images. The methodology used to identify and forecast coastal erosion in this project is shown in Figure 5.

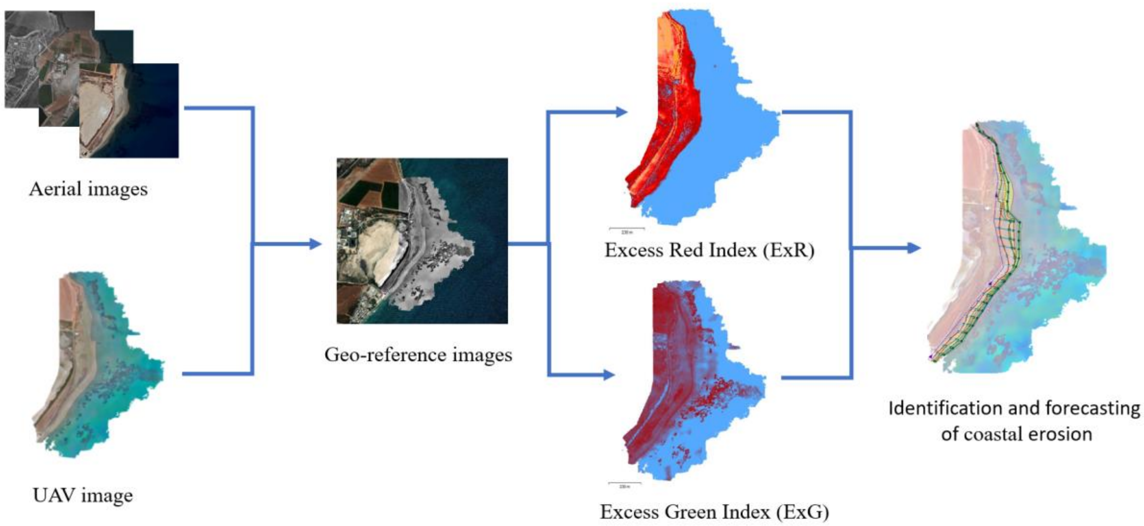

Figure 5 Project methodology

Image Segmentation using discriminating characteristics of interest from its background was used to address the change between sand and water for the coastline detection and water and vegetation for the Posidonia oceanica detection. Typical methods for image segmentation that are based on the visible spectral index include the Excess Green Index (ExG) [6] and the Excess Green minus Excess Red Index (ExGR) [7], which are used in this study.

3. RESULTS

Image Segmentation using the Excess Green Index (ExG) was used for quantifying the Posidonia oceanica in the sea and the Excess Red Index (ExR) was used in order to calculate the coastline of aerial and UAV images of Spyros Beach. The ExG and the ExR equations [6,7] were calculated using the radiometrically calibrated RGB reflectance values, instead of the RGB digital numbers.

The ExG index was computed using Equation 1.

$$ExG = 2g - r - b \text{ (Excess Green Index)} \quad (1)$$

where r, g, and b are the chromatic coordinates.

In order to get the chromatic coordinates, the values of each spectral band (R, G, and B) were normalized by dividing the highest value within the spectral band for the image being analyzed. The normalized pixel values range from 0-1 according to equations 2 to 4 [8]:

$$r = Rn / (Rn + Gn + Bn) \quad (2)$$

$$g = Rn / (Rn + Gn + Bn) \quad (3)$$

$$b = Rn / (Rn + Gn + Bn) \quad (4)$$

where Rn, Gn and Bn are the normalized RGB coordinates ranging from 0 to 1.

Rn, Gn, and Bn were obtained using equation 5:

$$Rn = R/Rmax$$
$$Gn = G/Gmax \quad (5)$$
$$Bn = B/Bmax$$

where: $Rmax = Gmax = Bmax = 255$

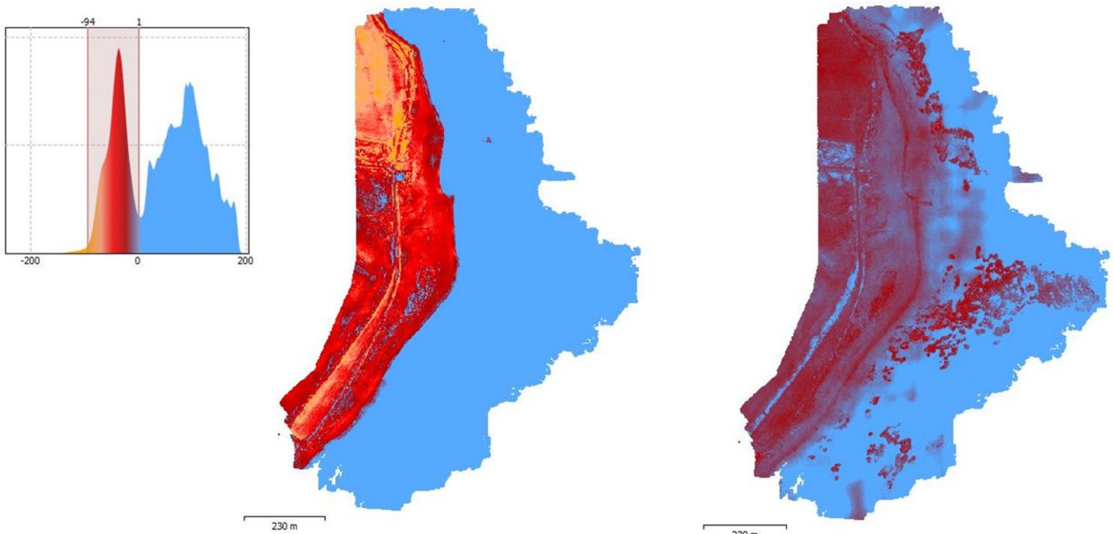

Figure 6: Left: Excess Red Index (ExR) to calculate the coastline of Spyros Beach. Right: Excess Green Index (ExG) to quantifying the Poseidonia seagrass

Figure 6 shows the results of the Excess Red Index (left), which features a clear coastline and the clear differentiation between land and water on the histogram and the Excess Green Index (right), which reveals the Posidonia oceanica in the water. After the geo-reference and digitization of the coastlines using the Excess Red Index from all images, a multi-layer file was produced in order to calculate and compare the coastlines over time. In comparing the coastline mapping, it was evident that the coastline is expanding, most likely through deposition of sand and sediment that generates a constant accumulation of sand that results in expanding the coastline over time. In Figure 7, the first image shows a comparison of the coastline from 1993 and 2021, the second image shows a comparison of the coastline from 2008 and 2021 and the third image shows a comparison of the coastline from 2014 and 2021. The last image is an overlap of all four coastlines from 1993, 2008, 2014 and 2021, that clearly shows the change in the coastline over time.

Figure 7: Aerial images from 1993, 2008 and 2014 compared with 2021 image

The Digital Shoreline Analysis System (DSAS) v5.0 software was used in conjunction with Esri ArcGIS desktop to calculate rate-of-change statistics from the 1993, 2008, 2014 and the 2021 images of the shoreline positions. The Digital Shoreline Analysis System provided an automated method for establishing measurement locations, performed rate calculations, provided the statistical data necessary to assess the robustness of the rates, and forecasting to generate a 10-year shoreline horizon and uncertainty band. DSAS generates transects that are cast perpendicular to the reference baseline at a user-specified spacing alongshore. The results of all calculations are output to a new rate feature class with the option to visualize results to a default binning standard or to scale to the extent of the data. Transect length can be autodetected and clipped to the shoreline data extent. Figure 8 shows that the coastline will continue to extend for the next 10 years, as a result of the accumulation of sand.

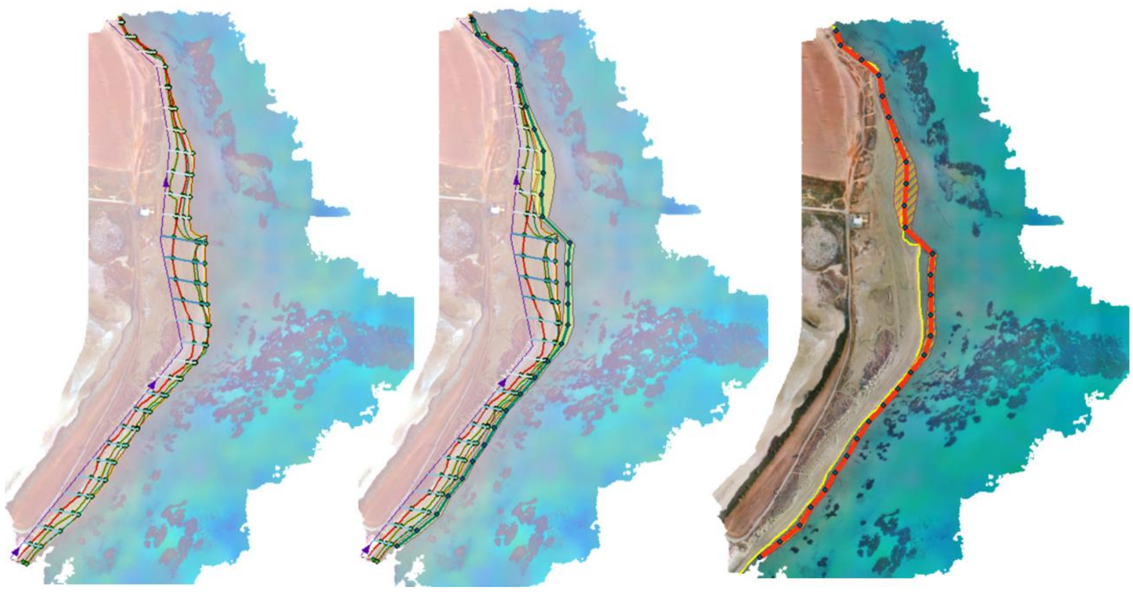

Figure 8: Transects of the shorelines of 1993, 2008, 2014 and 2021 including prediction model for the next 10 years

In order to examine the change in the level of Posidonia oceanica in the study area, the 1993 aerial image and the 2021 image taken by the UAV (figure 9, left and middle, respectively) were digitized using the Excess Green Index to show the difference of Posidonia oceanica over the three decades. The resulting image indicated that the location of the Posidonia oceanica did not change over time; however, it showed a reduction in the lower part of the image, as indicated in orange in figure 9 (right).

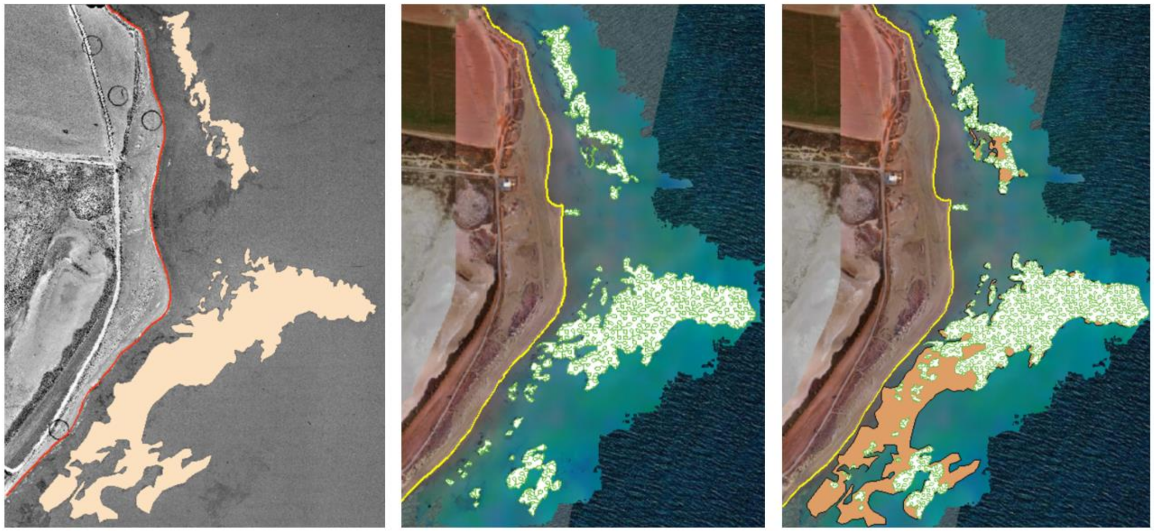

Figure 9 Extent of Posidonia oceanica from 1993 to 2021 images

4. CONCLUSIONS

As a result of the survey, it has been found that the methodology developed in this study can be used as a fast and accurate method to map possible coastline erosion using archived aerial and UAV images. It can also be used to identify any other features, such as Posidonia oceanica, that may affect erosion or expansion of coastlines. As well, it can be used to forecast any change in the selected area of study over time.

In this study, the results found that the coastline is expanding every year and will continue at a constant rate of expansion during the next 10 years. The study shows that erosion is not affecting the specific area, but rather that deposition of sand is expanding the coastline. The beach nourishment observed may be resulting from the increase in depth due to the loss of Posidonia oceanica, thereby changing the dynamics of sand deposits between the coastline and the sea generating energy to transport sand on the beach through the accumulation of sand instead of erosion. The study did not take into account any seasonal changes.

5. ACKNOWLEDGEMENT

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REFERENCES

[1] Yang, Z., Yu, X., Dedman, S., Rosso, M., Zhu, J., Yang, J., Xia, Y., Tian, Y., Zhang, G. and Wang, J. "UAV remote sensing applications in marine monitoring: Knowledge visualization and review". Science of The Total Environment, 155939 (2022).

[2] Marre, G., Holon, F., Luque, S., Boissery, P., and Deter, J. " Monitoring marine habitats with photogrammetry: a cost-effective, accurate, precise and high-resolution reconstruction method". Frontiers in Marine Science, 276. DOI: 10.3389/fmars.2019.00276, (2019).

[3] Themistocleous, K., and Anayiotos, A. Investigating the past using remote sensing techniques. Proc. SPIE 11863, Earth Resources and Environmental Remote Sensing/GIS Applications XII, 118630A (12 September 2021); https://doi.org/10.1117/12.2600227. (2021).

[4] Themistocleous, K., Mettas, C., Evagorou, E., and Hadjimitsis, D. G. The use of UAVs and photogrammetry for the documentation of cultural heritage monuments: The case study of the churches in Cyprus.Proc. SPIE 11156, Earth Resources and Environmental Remote Sensing/GIS Applications X, 111560I (3 October 2019); https://doi.org/10.1117/12.2533056. (2019).

[5] Themistocleous, K., Ioannides, M., Tryfonos, G., Pritchard, D., Cliffen, H., Katiri, M., Jončić, N., Osti, G., Rigauts, T., Ripanti, F. and Anayiotos, A., 2022, October. HBIM for cultural heritage: the case study of Panayia Karmiotissa Church. In Earth Resources and Environmental Remote Sensing/GIS Applications XIII (Vol. 12268, pp. 46-54). SPIE. doi.org/10.1117/12.2636331. (2022)

[6] Woebbecke, D. M., Meyer, G. E., Von Bargen, K. and Mortensen, D. A. "Color indices for weed identification under various soil, residue, and lighting conditions". Transactions of the ASAE, 38(1), 259-269. 10.13031/ 2013.27838 (1995).

[7] Meyer, G. E. and Neto, J. A. C. "Verification of color vegetation indices for automated crop imaging applications." Computers and Electronics in Agriculture. 63(2), 282–293, (2008). 10.1016/j.compag.2008.03.009

[8] Gée, C. Bossu, J. Jones, G. and Truchetet, F. "Crop/weed discrimination in perspective agronomic images." Computers and Electronics in Agriculture. 60(1),49-59, (2008) 10.1016/j.compag.2007.06.003.