

Assessing the Accuracy of Histogram Threshold and Band Ratio as a Shoreline Extraction Techniques from Low-resolution Sentinel-2 Satellite Imagery.

Prepared By

Mohamed Elmeligy¹, Ahmed Elrabbany², Saad Mesbah³, Mohmoud Hassan⁴, Mohamed Mohasseb⁵

¹⁻³⁻⁵ Arab Academy for Science, Technology, and Maritime Transport, AASTMT.

² Department of Civil Engineering, Toronto Metropolitan University. Ontario, Canada

⁴ Graduate Studies and Research Institute, Alexandria University, Egypt.

DOI NO. <https://doi.org/10.59660/50710>

Received 12/12/2024, Revised 04/01/2025, Acceptance 16/02/2025, Available online and Published 01/07/2025

المستخلص

تلعب المناطق الساحلية حول العالم دورًا مهمًا للبشرية في مختلف الجوانب. إذ إن الحفاظ على المناطق الساحلية يدعم بشكل حيوي الاقتصاد المحلي والعالمي من حيث مصايد الأسماك، والسياحة، والنقل، والأنشطة البشرية. تؤدي التغيرات المناخية السريعة الناتجة عن الرياح، والاحتباس الحراري، وارتفاع مستوى سطح البحر، والأنشطة البشرية مثل التشييد إلى تأثيرات سلبية، مثل تآكل السواحل، مما تسبب في تغييرات جذرية في الخطوط الساحلية. لذلك، فإن تبني إدارة المناطق الساحلية والمراقبة البيئية سيساعد في التخفيف من هذه التأثيرات السلبية.

ولضمان التنمية المستدامة في التخطيط والاستجابة للكوارث، من الضروري رسم خرائط وتصنيف التغيرات في الخطوط الساحلية. على الرغم من التقدم في الأقمار الصناعية الخاصة بالاستشعار عن بعد، إلا أن إدارة المناطق الساحلية تعاني من دقة منخفضة في الجوانب المكانية والزمنية عبر المنصات مفتوحة المصدر مثل MODIS و Landsat و Sentinel علاوة على ذلك، فإن صور الطائرات المسيرة عالية الدقة لا تزال محدودة، بالإضافة إلى العديد من التحديات والقيود.

يهدف هذا البحث إلى تقييم دقة تقنيات استخراج الخط الساحلي، مثل العتبة التوزيعية (Histogram Threshold) ونسبة الحزم الطيفية (Band Ratio) من صور القمر الصناعي Sentinel-2 منخفضة الدقة، باستخدام الخط الساحلي المستخرج من صور الطائرات المسيرة عالية الدقة كمرجع أرضي.

تم تطبيق تحليل التباين (ANOVA) لاختبار الفروق في الانحرافات بين مختلف التقنيات، بالإضافة إلى حساب الجذر التربيعي لمتوسط الخطأ (RMSE) لقياس الفروقات بين الخطوط الساحلية المستخلصة والمرجعية.

Abstract

Coastal regions worldwide have a significant role for humanity in various aspects. Maintaining coastal zones vitally supports the local and global economy concerning fisheries, tourism, transportation, and human activities. Rapid climate changes due to wind, global warming, sea level rise, and human activities such as construction have negative impacts, such as coastal erosion,

which has caused dramatic changes in shorelines. Therefore, adapting coastal management and environmental monitoring will assist in mitigating the adverse effects. To ensure sustainability development in planning and disaster response, it is essential to map and classify shoreline changes. Despite advances in remote sensing satellites, coastal zone management suffered from low resolution in both spatial and temporal aspects from open-source platforms such as MODIS, Landsat, and Sentinel. Moreover, high-resolution drone images are still limited, in addition to many challenges and restrictions.

This paper aims to evaluate the accuracy of shoreline extraction techniques such as histogram threshold and band ratio from the low-resolution Sentinel-2 satellite imagery using shoreline delivered from high-resolution drone images as a ground truth.

Analysis of Variance (ANOVA) has been applied to Testing the differences in deviations between various techniques. In addition to Root Mean Square Error (RMSE) to measure the discrepancies between the derived and reference shorelines. As a result of the evaluation of both histogram threshold and band ratio as a shoreline extraction method from satellite regarding the reference shoreline extracted from the drone, the main finding showed that the threshold is better than band ratio shoreline extraction technique from low-resolution sentinel-2 satellite imagery.

Keywords: Shoreline extraction, Sentinel-2, Drone, Histogram threshold, Band ratio technique.

1- Introduction

Coastal regions globally are essential and serve a crucial function for humanity across various domains. Most of the Earth's surface is made up of seas, oceans, rivers, and lakes. Consequently, coastal areas play a vital role in the local economy, contributing to fisheries, tourism, transportation, and agriculture and providing sources of food and energy. Currently, the coastline is undergoing changes due to erosion caused by natural events like storms, wind, and rising sea levels, alongside human activities such as construction. Mapping and classifying coastal areas are essential for shoreline detection, which supports coastal management, environmental monitoring, and the prediction and protection against significant changes in these regions (Sesli, 2010).

More than 50% of the world's population lives along coasts and river mouths, relying heavily on natural resources and the environment for their livelihoods (Quang et al., 2021). Coastal regions are important for multiple fields, such as coastal management, environmental monitoring, and economic development, including transportation and tourism (Tegar and Saut Gurning, 2018). However, the coastline's dynamic spatial and temporal variation is a significant concern due to erosion and accretion threats (Tercan and Dereli, 2021). Coastal zone management plays a vital role in sustainable development and environmental preservation. Considering global warming, it is crucial to monitor coastal zones and manage shoreline extraction. The shoreline is the boundary where land meets a water body (Kafrawy et al., 2017). Research demonstrates that over 80% of beaches worldwide experience coastal erosion caused by natural processes such as winds, waves, currents, tides, and human activities. To track changes along the coast, it is essential to detect shorelines, which mark the intersection between the water and the Earth's surface and serve as evidence for shoreline change (Quang et al., 2021).

Monitoring coast profiles is essential to identify the factors driving these changes. This allows researchers to develop sustainable coastal management strategies, which are crucial for achieving Integrated Coastal Zone Management (ICZM) (Saad et al., 2022). Remote sensing technology has enhanced environmental monitoring, particularly in shoreline extraction. Although satellite imagery offers excellent spatial coverage and frequent temporal updates for observing macroscale changes, it is often hindered by atmospheric interference, particularly at lower spatial resolutions. However, drone-based technologies went a step further by providing high-resolution images that capture the most subtle details generally lost in satellite data or at least when free low-resolution satellite images were used. This benefit is particularly essential in the mapping of dynamic coastal environments.

Recent studies among sources currently revealed the effectiveness of drones in enhancing surface water delineation. For example, the mapping of urban surface water utilizing very high-resolution images through super-pixel segmentation and target detection represents how drone imagery can augment satellite data by refining boundary delineation. The integration of satellite imagery with drone technology suppresses everyone's disadvantages while highlighting an integrated approach toward shoreline dynamics of higher order. Other studies confirmed that continued advancement in the integration of such systems remains of vital importance for enhancement in accuracy in shoreline extraction (Bhatt, 2022).

2- Literature Review

Manual digitization enhances the accuracy and quality of shoreline extraction from high-resolution satellite imagery. It offers precise control, enabling scientists to apply specific techniques to different geographic features. Human involvement is essential at this level to accurately capture the subtle variations of the shoreline, which may not be guaranteed through automated methods, particularly in complex coastal regions with high rates of land loss and accretion due to changing environmental conditions (Mahato, 2024).

Among the classifications of sea versus land derived from remote sensing images, Sea-Land Segmentation (SLS) is a type in which boundary pixels that distinguish different classified areas reliably identify the coastline. Generally, thresholding refers to a traditional, feasible technique for performing SLS. It is an automatic and easy-to-implement method that offers high efficiency. It relies on the selection of subjective appropriate spectral bands regarding the spectral properties of water and land. It can create a model that effectively divides the image into two main identical areas, namely, water and land (Vitousek et al., 2023).

Based on different circumstances, when defining coastline objects of various types, the selection of indices for identifying the coastline features still needs investigation. These indices can only benefit the sea-land segmentation, and other methods need to be combined to recognize the coastline extraction. Therefore, in the present study, histogram threshold in conjunction with band ratio techniques, has been employed to ensure the selection of accurate indices for shoreline extraction (Zhou et al., 2023).

3- Research Problem

Resolution and data availability are the two most influential variables when it comes to evaluating the effectiveness of an imagery source for shoreline delineation. The no-cost, low-resolution satellite imagery, like Sentinel-2, became extremely popular simply because it was free and increasingly available with an expanded temporal range. However, the limitations in spatial resolution may restrict the accurate mapping of shoreline boundaries in those complex coastal environments that show high variations in coastal vegetation and landform types (Lv et al., 2024).

On the contrary, high-resolution drone imagery ensures higher levels of subtle variation of details for the exact mapping of shorelines and other features in the coastal area. This ability is emphasized by recent analyses that reveal substantial enhancements in classification accuracies when employing data derived from the Unmanned Aerial Vehicle (UAV) techniques.

Therefore, there are various shoreline extraction techniques from low-resolution satellite images with different accuracy regarding to the shoreline from high-resolution drone images. It is very complex to select a suitable shoreline extraction technique from satellite imagery according to various circumstances such as the data nature and the coastline morphology in addition to the low quality of satellite imagery resolution.

4- Research Objectives

- To apply the manual digitization on screen to extract high-resolution shoreline from the drone images.
- To apply the automatic extraction of shoreline from the low-resolution satellite imagery such as histogram threshold and band ratio.
- To compare the various techniques with the reference shoreline using ANOVA test and RMSE.

5- Research Methodology

- To collect high-resolution drone images of the interested area and download free low-resolution Sentinel-2 satellite imagery from the Copernicus Open Access Hub.
- To process the high-resolution drone images using Drone2Map software to get a Digital Surface Model (DSM) and True Ortho mosaic.
- To apply the best technique to extract the shoreline accurately from the drone images with concern to be used as a reference benchmark.
- To apply the most common automatic shoreline methods on the low-resolution Sentinel-2 satellite imagery using ArcGIS Map algorithms.
- To validate the accuracy of the automated shoreline extraction Sentinel-2 satellite.

A theoretical framework is presented to demonstrate the workflow, as shown in Figure 1, which outlines the phases of the study. The process begins with gathering data from both drone and Sentinel-2 satellite images. Next, processing conducted to prepare the data. After that, shoreline extraction techniques applied-either manually for drone images or automatically for satellite images-using ArcGIS software, including histogram thresholding and band ratio.

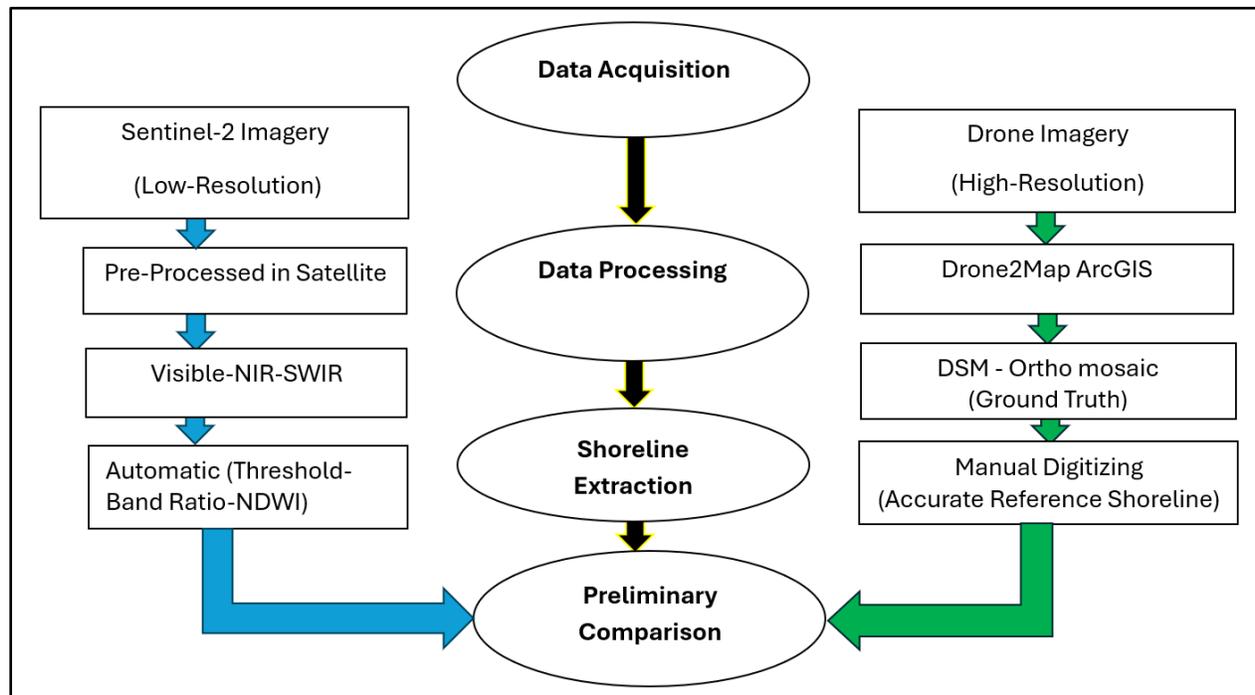


Figure (1) Theoretical Framework of Workflow.

6- Data and Study Area

This study focuses on a coastal area of Coronation Park located north of Lake Ontario in Canada. Two datasets were collected: high-resolution images captured by P1 camera on a small UAV on 22 October 2022, and low-resolution Sentinel-2 satellite images downloaded on the same date. The Sentinel-2 data was sourced as open-source material through the Copernicus-Sentinel Hub, provided by the European Space Agency. The projection used is Universal Transverse Mercator (UTM) zone 17N, with EGM96 as the geoid for elevation, and the World Geodetic System (WGS) 1984 as the ellipsoid and datum.

7- Drone Data Processing

Drone images have been processed using ArcGIS Drone2Map software by uploading the captured high-resolution drone images. The project was created, and then pre-processing adjustments such as camera calibration, georeferencing, and checking the parameters of final products were made. Once the adjustment is applied, it is saved in the project option and ready to be used during the processing. Running the Drone2map tool to process the high-resolution images delivered by P1 camera on drone will take longer processing time depending on the machine performance used, such as CPU or GPU, in addition to the quality required to generate the desired products, for example, DSM or True Ortho products as shown in Figure 2.

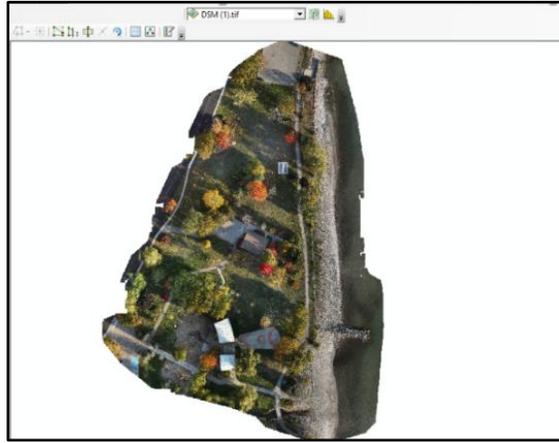


Figure (2) DSM Product from the Drone.

7.1 Shoreline Extraction from Drone

Due to the high-resolution of the drone images, manual digitizing has been used for shoreline extraction as shown in Figure 3. The drone shoreline is considered the reference ground truth in the comparison.



Figure (3) The Extracted Shoreline from the Drone.

8- Sentinel-2 Shoreline Extraction

Despite the advancement in satellite imagery and its ability to cover wide areas, these images remain suffering from their low resolution in both spatial and temporal compared to the high-resolution imagery provided by drones. As a shoreline extraction technique used with drones, manual digitizing for satellite shoreline extraction is ineffective. Therefore, the most effective technique for extracting shorelines from Sentinel 2 satellite images is to use the automatic methods in ArcMap, employing multiple functions and algorithms such as histogram thresholding, band ratio. Coastline delineation using remote sensing techniques depends on the different spectral behaviors or responses of water and other land surfaces at various wavelengths. Generally, water bodies absorb most of the radiation energy in the spectrum's Near Infrared (NIR) and Short-Wave Infrared (SWIR) zones. Thus, the reflectance of water is almost equal to zero in these wavelengths.

Meanwhile, the reflectance of various land covers in NIR and SWIR, such as Band 3 and 8 in the Sentinel-2 satellite, is relatively high and greater than that of water, as indicated in Figure 4.

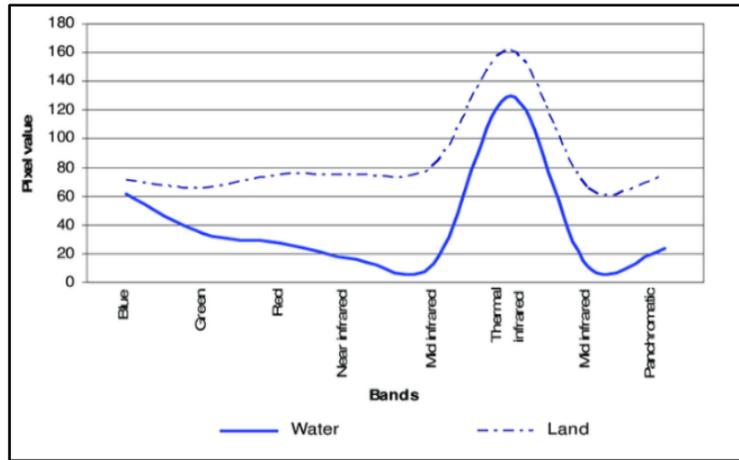


Figure (4) Spectral Behavior of Water and Land Surfaces in Different Wavelengths.
Credit: (Hassaan, 2012).

8.1 The Histogram Threshold Technique of the SWIR Band

The threshold technique was determined from the band 11 histogram. To select an appropriate threshold value separating water from land, sample pixel brightness values were examined using an inquire cursor in various parts of the image. Thereafter, all the image pixels were classified, where the pixels with a Digital Number (DN) value less than the threshold value were classified as water and given “1,” and those with DN values larger than the threshold value were classified as land and given “0.” The histogram Threshold as a binary image was produced in which water pixels are given a “1” value while land pixels are given a “0” value, as illustrated in Figures 5.

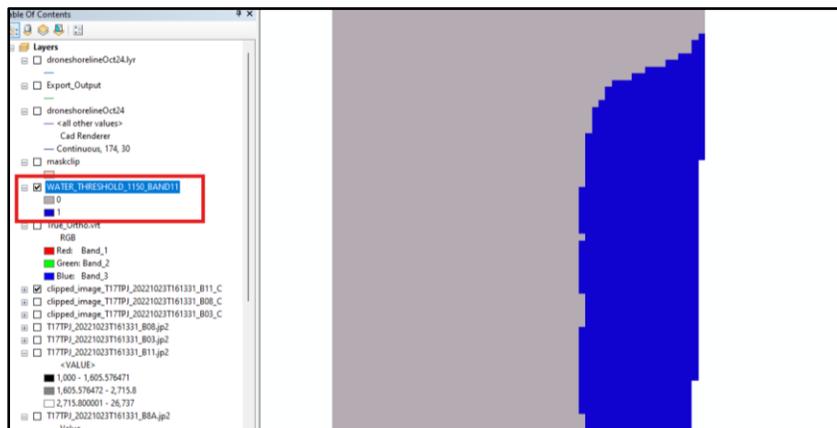


Figure (5) The Final Product of Threshold Technique.

8.2 The Band Ratio Technique

The second step is to calculate two band ratios, the Green/NIR ratio (band 3/band 8) to separate land cover from water and the Green/SWIR ratio (Band 3/band 11) to separate non-land covers from water. Due to the low reflectance of water and high reflectance of land in NIR (band 8) and

SWIR (band 11) and the relatively lower reflectance of water in band 3 than other land covers, these ratios will be greater than one for water and less than one for land. According to these methods of coastline delineation, the band ratio equation will be applied once for bands 3 and 8 and another time for bands 3 and 11, as shown in Figure 6.

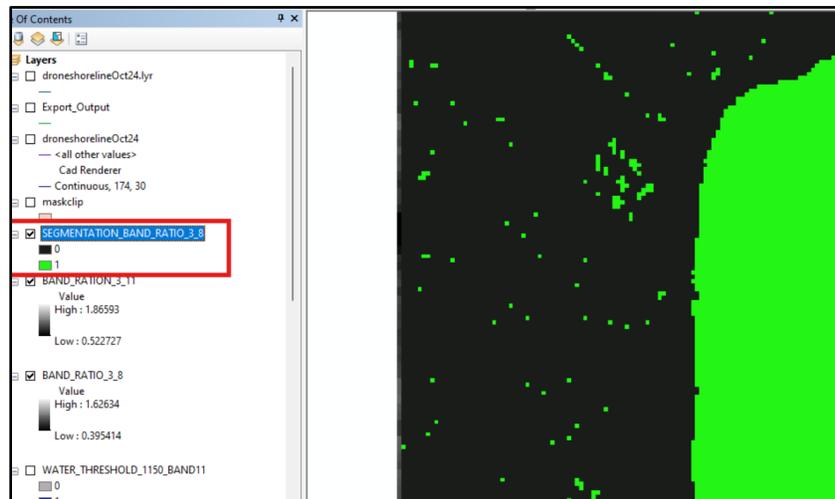


Figure (6) The Band Ratio Classification.

9- The Assessment Methodology

The satellite-derived shoreline positions extracted from each technique were compared to the drone-derived shoreline as a reliable reference. For this purpose, the following analysis approach was applied:

- a- Splitting both the derived and reference shorelines into an equal number of line segments through the Split tool in the Editing toolbar.
- b- Calculating the distance between the mid-point of each line segment at the derived shoreline and the mid-point of the closest line segment of the reference shoreline through the Near tool in the Proximity Analysis toolset.
- c- Testing the differences in deviations between various techniques for delineating shoreline through Analysis of Variance (ANOVA).

Measuring the discrepancies between the derived and reference shorelines Through Root Mean Square Error (RMSE). Generally, higher values of RMSE indicate low agreement between the derived and reference shoreline and, thus, low accuracy of the shoreline delineating technique, and vice versa.

10- Results and Discussion

The comparison was made between more than two shorelines of the coast area extracted by several methods such as threshold histogram and band ratio. The best analysis was the ANOVA to detect if there is a significant difference between the mentioned techniques or not. Therefore, the hypothesis has been set to measure the existing considerable difference between each derived shoreline and the reference shoreline.

Hypothesis

H₀: The mean deviation between each of the three derived and reference shorelines is equal.

H₁: The mean deviation of the three derived and reference shorelines are not all equal.

Table (1) Results of Analysis of Variance.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	2	7780481	3890241	152.21	0.000
Error	90	2300308	25559		
Total	92	10080789			

Table 1 shows the ANOVA results. Since the p-value is very small (< 0.001), the null hypothesis must be rejected, and an alternative hypothesis must be accepted that highlights that there are significant differences between the deviation of the three applied techniques of shoreline extractions from the low-resolution Sentinel-2 satellite images. After that, a metric used to evaluate the accuracy of quantitative data was Mean Absolute Error (MAE) because it calculates the average of the absolute differences between the extracted shoreline techniques values from the satellite and the actual drone shoreline as a reference value. The lower the MAE, the closer the shoreline extraction technique values to the drone shoreline reference. The MAE calculated the accuracy regardless of the direction of errors, whether they have positive or negative values. For that reason, it is not affected by the outlier’s value due to the individual differences being weighted equally. Moreover, it was necessary to use another metric to magnitude the difference errors derived from satellite shorelines and reference one by squaring the different values. This metric is the Mean Square Error (MSE), which is more sensitive to the large outlier errors and then brings the metrics back to the original scale of the data to simplify the interpretation of the difference using RMSE, which is the square root of MSE.

While ANOVA highlighted that the three different methods used to extract satellite shorelines automatically have significant differences, the MAE, MSE, and RMSE were applied to decide which one of the derived shorelines is close to the reference shoreline, as shown in Table 2. RMSE emphasized that the shoreline extracted by threshold techniques revealed the highest level of accuracy, recording the minimum MAE of 12.26 m and the lowest RMSE of 13.19 m. Besides the band ratio approach, which is the least effective method for shoreline extraction due to its erroneous values stemming from geometrical resolution in distinguishing land from water, it exhibited the lowest accuracy, with a mean absolute error of 23.87 and the highest RMSE of 25.03.

Table (2) Summary Statistics of Deviation Between Derived and Reference Shorelines.

Statistic	Band thresholding	Band Ratio
Average (MAE)	12.26	23.87
Maximum	17.79	31.21
Minimum	0	5.03
STDV	4.87	7.54
RMSE	13.19	25.03

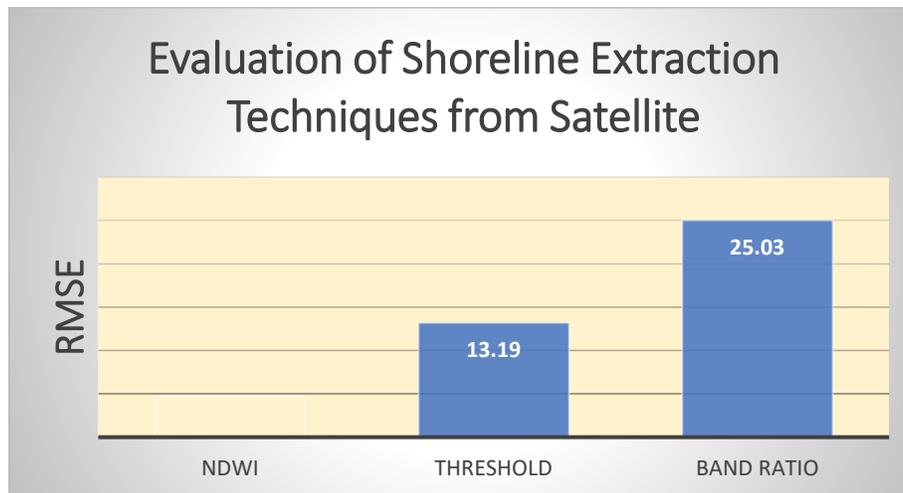


Figure (7) The Deviation Errors of Satellite Techniques from Drone.

Figure 7 represents the errors delivered by different techniques of shoreline extraction from satellites. The previous comparison evaluated the differences in techniques such as threshold and band ratio regarding drone shoreline as a reference ground truth. The result showed that the best highlighted automatic technique for shoreline extraction from satellite imagery was the histogram threshold technique.

11- Conclusion

high-resolution images of Coronation Park, a coastal area of Lake Ontario, Canada, were acquired through the DJI P1 camera installed on the DJI M300 RTK Drone. The area of interest was complicated morphology types, including sands, gravels, mangroves, and rocks with coastal windings. The spatial resolution of the collected images was 0.006 m. ArcGIS Drone2Map software was used to process the drone-based images, resulting in a high-resolution DSM.

The methodology was set regarding the high-resolution P1 imagery to be a ground truth in the comparison and evaluation. Several indices were tested to select the best shoreline extraction technique for the purposes of evaluation and assessment using multiple statistical analyses.

The statistical results showed that the different methods used for automatic extraction of satellite-based shorelines have significant differences. The histogram threshold technique was the best method for shoreline extraction from Sentinel-2 satellite imagery, resulting in the smallest MAE of 12.26 m and the lowest RMSE of 13.19 m, in comparison with the reference shoreline.

References

- Ahmet Sesli, F., 2010. Mapping and monitoring temporal changes for coastline and coastal area by using aerial data images and digital photogrammetry: A case study from Samsun, Turkey, International Journal of the Physical Sciences.
- Bhatt, P.P., 2022. Fine Scale Mapping of Laurentian Mixed Forest Natural Habitat Communities Using Multispectral Naip And Uav Datasets Combined with Machine LEARNING METHODS.

- Michigan Technological University, Houghton, Michigan.
<https://doi.org/10.37099/mtu.dc.etr/1503>
- Hassaan, 2012. Geographical Analysis of the Impacts of Shoreline Changes Using Remote Sensing and GIS Techniques. Case Study: Rosetta Nile Branch Promontory, Egypt. *The Arabian Journal of Geographical Information System* 5.
 - Kafrawy, S., Basiouny, M., Ghanem, E., Taha, A., 2017. Performance Evaluation of Shoreline Extraction Methods Based on Remote Sensing Data. *Journal of Geography, Environment and Earth Science International* 11, 1–18. <https://doi.org/10.9734/jgeesi/2017/36233>
 - Lv, Z., Nunez, K., Brewer, E., Runfola, D., 2024. Mapping the tidal marshes of coastal Virginia: a hierarchical transfer learning approach. *GIsci Remote Sens* 61. <https://doi.org/10.1080/15481603.2023.2287291>
 - Mahato, P.S., 2024. A Study of Morphological Changes in the Coastal Areas and Offshore Islands of Sudarban Coastline Using Remote Sensing.
 - Quang, D.N., Ngan, V.H., Tam, H.S., Viet, N.T., Tinh, N.X., Tanaka, H., 2021. Long-term shoreline evolution using dsas technique: A case study of Quang Nam province, Vietnam. *J Mar Sci Eng* 9. <https://doi.org/10.3390/jmse9101124>
 - Saad, R., Kallas, A., Gérard, J.A., Gérard, P., 2022. Importance of Beach Evaluation for Integrated Coastal Zone Management: A Case Study of Tyre Southern Lebanon. *Bulletin de la Societe Royale des Sciences de Liege* 91, 59–83. <https://doi.org/10.25518/0037-9565.10907>
 - Tegar, D., Saut Gurning, R.O., 2018. Development of Marine and Coastal Tourism Based on Blue Economy. *International Journal of Marine Engineering Innovation and Research* 2. <https://doi.org/10.12962/j25481479.v2i2.3650>
 - Tercan, E., Dereli, M.A., 2021. Monitoring of marble quarries expansion and land cover changes using satellite images and gis on a rural settlement of burdur province, turkey. *El-Cezeri Journal of Science and Engineering* 8, 741–750. <https://doi.org/10.31202/ecjse.868373>
 - Vitousek, S., Vos, K., Splinter, K.D., Erikson, L., Barnard, P.L., Castelle et al., 2021, 2023. A Model Integrating Satellite-Derived Shoreline Observations for Predicting Fine-Scale Shoreline Response to Waves and Sea-Level Rise Across Large Coastal Regions. *J Geophys Res Earth Surf* 128. <https://doi.org/10.1029/2022JF006936>
 - Zhou, X., Wang, J., Zheng, F., Wang, H., Yang, H., 2023. An Overview of Coastline Extraction from Remote Sensing Data. *Remote Sens (Basel)*. <https://doi.org/10.3390/rs15194865>