Advanced UAV
http://publish.mersin.edu.tr/index.php/uav
e-ISSN 2822-6976

Monitoring coastal erosion and sediment accumulation in the Kızılırmak Delta using UAVs and photogrammetry

Erdem Emin Maraş *[1], **Kübra Nur Karafazlı** [2]

[1] Samsun University, Department of Flight Training, Türkiye, erdem.maras@samsun.edu.tr
[2] Atakum Municipality, Directorate of Urbanism, Türkiye, kubranurkarafazli@gmail.com

Cite this study: Maraş, E. E., & Karafazlı, K. N. (2024). Monitoring coastal erosion and sediment accumulation in the Kızılırmak Delta using UAVs and photogrammetry. Advanced UAV, 4 (1), 42-52.

Keywords
Coastal change
UAV
Photogrammetry
Kızılırmak Delta

Research Article
Received: 28.03.2024
Revised: 05.05.2024
Accepted: 15.05.2024
Published: 14.06.2024

check for updates

Abstract

Areas around the coast and delta offer significant resources and business prospects, but they are also susceptible to human activity and natural calamities. In order to tackle these concerns, it is crucial to consistently observe and analyze coastal and delta regions to comprehend the ongoing alterations and enforce essential measures to safeguard the ecosystem and the communities reliant on it. Unmanned aerial vehicles (UAVs) possess the capacity to efficiently and inexpensively cover vast areas. UAVs, or unmanned aerial vehicles, have gained significant popularity in recent years for the purpose of monitoring and investigating coastal and delta regions. The Kızılırmak Delta in Türkiye has been adversely affected by human activity, including the construction of dams and the extraction of sand, resulting in a reduction in the delta's dimensions and biodiversity. This study employs photogrammetric techniques and UAVs to observe and analyze the alterations occurring in the Kızılırmak Delta in Türkiye. Consequently, the shorelines generated using photogrammetric techniques in the region where the spurs were built are being compared to the shorelines obtained by terrestrial approaches. Research indicates that the construction of spurs effectively halted coastal erosion in specific regions. However, in other locations, coastal regression persisted, and sediment buildup led to movement of the coastline towards the sea in certain sections. This methodology can be employed to formulate efficient strategies for safeguarding and revitalizing the Kızılırmak Delta and analogous regions.

1. Introduction

Coastal regions have historically served as focal points of human civilization because of their proximity to water supplies and the various opportunities they provide for activities such as farming, livestock rearing, and transportation [1]. These regions remain appealing because of their economic and social advantages, such as tourism, commerce, and fishing [2]. Nevertheless, the rising desire for living near the coast and economic prospects has exerted stress on these areas, resulting in shifts in both marine and terrestrial directions over time [3]. The coastal ecosystem can be significantly affected by changes in the shoreline, as it is the interface between the land and sea [4]. These changes can arise from both natural and anthropogenic activity, such as the development of new residential and transportation facilities and the expansion of tourism [3, 5, 6]. These modifications can result in reduced accessibility of drinkable water, heightened water contamination, and an elevated likelihood of water-related calamities [7]. In order to mitigate these risks, it is imperative to prioritize the preservation and long-term viability of water resources by closely monitoring the dynamics of coastal movements. This should be considered an integral part of any comprehensive coastal management strategy [8].

Delta regions, created via the deposition of sediment transported by rivers, can be affected by alterations in sedimentation caused by natural occurrences like climate change and coastal erosion, as well as human actions such as the construction of dams and the extraction of sand from rivers [9]. Regular monitoring is crucial for protecting the ecosystems of these dynamic and ever-changing wetlands, as well as for implementing appropriate precautions [6].

Delta regions possess considerable importance due to their distinctive environmental forms and rich biodiversity [10]. These areas are created by the deposition of alluvium at the river mouths and are continuously molded by the materials transported by the rivers and other variables like wave currents [11]. The forming process of Delta coasts causes alterations in both the directions of the land and the sea.

Due to their delicate and vulnerable nature, wetlands, including delta regions, require continuous monitoring and protection. It is essential to establish management strategies to effectively address any possible risks or dangers. Decreases in water resources in these areas can exacerbate the impacts of climate change [12]. The Kızılırmak Delta, which is used as the study area in this research (Figure 1), was formed by the alluvium carried by the Kızılırmak River as it flows from its source at Kızıldağ in Sivas province through several provinces and into the Black Sea at Bafra Cape. The Kızılırmak Delta is one of Türkiye 's important delta areas due to its large size and diverse species of flora and fauna [13].

The test area for this study is located east of the Kızılırmak River in the delta region. Real orthophotos were produced through photogrammetric acquisition of a stretch of approximately 1 km in the area where spurs are present. In addition, local measurements taken by the State Hydraulic Works (SHW) cover a larger area to the east of the Kızılırmak River (Figure 1).

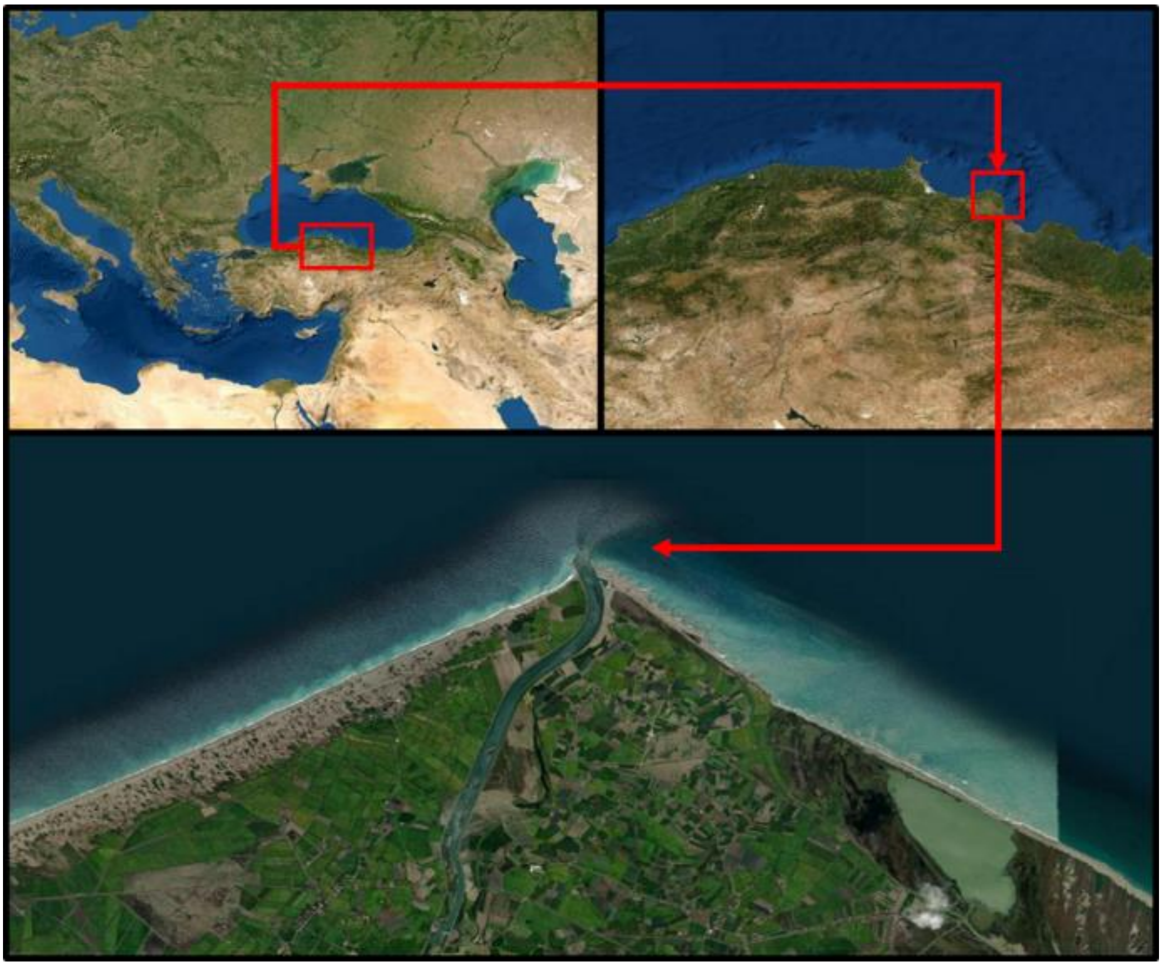

Figure 1. The general view of the study area.

1.1. Aim of the study

The Kızılırmak River is home to several dams and hydroelectric power stations. These dams have significantly reduced the amount of sediment carried by the river and have halted the growth of the delta [14]. Prior to the construction of the dams, the sediment flow to the Black Sea was 23.1 million tons per year (until 1960), but this amount has decreased by more than 98% since the dams became operational [11]. The Kızılırmak Delta experienced a cessation of growth when the dams were filled with water, followed by soil loss due to coastal erosion and a regression in the land direction over time [15, 16].

Another factor contributing to the decline of the Kızılırmak Delta is the establishment of sand quarries along the river. The geological structure of the river consists primarily of fine and coarse sand, which is extracted and used as raw material by construction sites. Sand quarries, the first of which became operational in the late 1970s, have been added at various times and at least 51.5 million tons of sand have been extracted until the 2000s. These sand extractions have played a significant role in the regression of the delta towards the coast. With the prohibition of sand extraction in the Ramsar Convention-protected area in 1998, it has been observed that the coastline has moved in the direction of the sea in some parts [17, 18].

To address the erosion and changes in the coastline caused by increased human intervention in the Kızılırmak Delta, various legal regulations and protective structures such as spurs have been implemented. In the wake of these measures, studies aimed at evaluating their effectiveness have come to the forefront. The goal of this study is to determine the coastline of the Kızılırmak Delta using UAV images and to assess the changes in the coastline by comparing these results to local measurements taken in previous years.

The Bafra Plain Irrigation Project Directorate, affiliated with the SHW VII Regional Directorate, regularly monitors the changes in the coastline east of the Kızılırmak River due to coastal erosion. In response to the threat of rapid withdrawal by the sea, precautions were taken in the form of the construction of three spurs in 1999. The continued eastward coastal erosion over time has led to an increase in the number of spurs constructed. In this process, risky areas have been identified through regular terrestrial measurements. From these measurements, coastline data for certain years from 2001 to 2018 have been produced. By evaluating these shorelines together with the shoreline produced from the true orthophoto image of the area, it is possible to observe the coastal activity after the construction of the spurs.

1.2. Literature review

In recent years, UAVs have become increasingly popular as a means of mapping and monitoring coastal areas. An important benefit of using UAVs is their capacity to obtain high-resolution imagery and produce digital elevation models (DEMs) with exceptional spatial resolution quickly and cost-effectively. Conversely, conventional approaches to aerial photogrammetry including helicopters or airplanes might be excessively costly and difficult to implement for smaller regions [19]. When compared to traditional photogrammetry and remote sensing instruments, UAVs are more practical for gathering data in small areas [20].

Multiple studies have shown that utilizing UAVs is highly beneficial in monitoring coastal regions. For instance, Ishaand and Adip [21] employed unmanned aerial vehicles to detect alterations in the shoreline at Regency Beach, Port Dickson. They concluded that this technological approach served as a valuable substitute for observing modifications in coastal areas. Casella et al. [22] employed drones to assess alterations in the topography of a specific coastal area in Italy. Their study revealed that this technology offered novel perspectives on the mechanisms behind both natural and human-induced changes in beach topography. Chapapria et al. [23] using UAVs to observe and track the process of coastal erosion along the Spanish Mediterranean coast. This was done with the intention of assisting in decision-making and the management of coastal areas. The method was determined to be appropriate for quantifying moderate to minor alterations along the coast and was carried out with minimal financial expenditure. There are also literature reviews including the usage and effectiveness of UAVs in coastal monitoring. In one of these studies Ventura et al. [5] reviewed the emerging applications of low-cost aerial platforms in environmental sciences, including the assessment of vegetation dynamics, wildlife research, and habitat mapping. Yang et al. [24] analyzed 1130 articles on the application and research advances of UAV remote sensing in marine monitoring and reviewed its use in marine mapping, environmental and disaster monitoring, and marine wildlife monitoring.

In addition to the studies mentioned above, UAVs have also been used for other applications in coastal areas. For example, Papakonstantinou et al. [25] used object-based fuzzy logic classification and UAV imagery to classify different elements in two different coastal areas and found that UAV photogrammetry is a powerful tool for the classification and mapping of coastal morphology with high precision data. Kokeza et al. [26] used Automatic building footprint extraction from UAV images using neural networks. Yoo and Oh [27] employed UAV photogrammetry to measure the extent of coastal erosion in beach regions and discovered that this technology offered significant 3D data for beach management and decision-making purposes. In their study, Mancini et al. [28] investigated the application of UAVs for generating high-resolution Digital Elevation Models (DEMs) in coastal regions. They conducted a comparison between the data obtained from UAVs and LIDAR, and concluded that UAVs can provide accurate DEMs with high precision at a reduced cost compared to LIDAR. Laporte-Fauret et al. [29] investigated the utilization of UAVs for generating accurate models in extensive regions at a minimal expense. UAV have been used in coastal areas to map river channels [30], generate DSM (digital surface model) of a beach dune system [28], and investigation of aeolian sand dune formation and evolution [31]. The researchers conducted a comparison of the image sensitivity between two distinct kinds of UAVs and determined that the DJI Phantom 4 exhibited superior findings compared to the DJI Phantom 2. This study showcased the capability of UAVs to produce accurate data in extensive areas with efficiency and cost-effectiveness.

This study contributes to the existing research by specifically examining the Kızılırmak Delta, a region in Türkiye known for its rich and varied biodiversity [32]. The objective of the study is to assess the alterations in the Kızılırmak Delta coastline by utilizing UAV imagery and to compare these alterations with past terrestrial observations. This technique offers a distinct viewpoint on the impact of protective structures and other human interventions on the delta region, as well as the possibilities for utilizing UAVs in monitoring.

The present study provided numerous contributions to the field of utilizing UAVs for coastal measurement and monitoring:

- The study specifically examined the Kızılırmak Delta, an exceptional and richly diverse region in Türkiye that has not been fully investigated utilizing UAVs.
- The study employed a fusion of UAV photography and terrestrial measurements to assess the temporal variations in the coastline, offering a comprehensive perspective on the area's dynamics.
- The study conducted a comparison between the sensitivity and accuracy of the real orthophoto image obtained from UAVs and measurements taken from the ground. The results demonstrated that UAVs are a reliable instrument for measurements.
- The study examined the impact of protective structures and other human interventions on the delta region, offering significant insights for management and decision-making purposes.
- •The study emphasized the capacity of UAVs to reduce the need for on-site work and generate data in an expedient manner, rendering them a cost-efficient and pragmatic choice for monitoring coastal regions.
- The study highlighted the efficacy of UAVs in supplying digital foundational data for diverse research endeavors, as the authentic orthophoto image has coordinates for every each pixel.
- The study emphasized the capacity of UAVs to rapidly and effortlessly assess the hazards associated with coastal erosion, facilitating prompt and efficient response.

In summary, the present study has shown that UAVs are highly effective in measuring and monitoring coastal environments, offering vital insights for the management and preservation of these ecosystems.

2. Material and method

The study area was selected to be the region east of the Kızılırmak River, where the spurs are situated. This choice was based on prior research that utilized traditional terrestrial methodologies and demonstrated that this area exhibits the most significant and active shoreline alterations [33]. The study utilized a DJI Phantom-4 UAV (Figure 2) to generate the shoreline data for 2019. This data was then compared to the existing data collected by precise measurements conducted by the SHW VII Regional Directorate. In order to generate an accurate orthophoto image of the designated region, photos were captured using an unmanned aerial vehicle (UAV) and subsequently processed utilizing Pix4D software.

Figure 2. DJI Phantom 4 model UAV taking aerial photo.

In photogrammetric applications, it is important to establish ground control points (GCPs) in the area where images will be taken before the photos are taken. As a matter of fact, GCPs are a mandatory factor used to generate an accurate photogrammetric model. For this study, 12 GCPs were homogeneously distributed in the application area, as shown (Figure 3).

The coordinates of these points were measured using a Topcon GR-5 CORS and are listed in Table 1. The images were then acquired using a UAV.

The flights were conducted in two blocks using a DJI Phantom 4 UAV, which is capable of both fully autonomous and manual flight. The total flight time for the study was approximately 18 minutes on average. The images were processed using Pix4D Mapper software, resulting in the production of a digital elevation model (DEM), a 3D mesh model, and a true orthophoto image of the area.

The evaluation phase of the captured images involves creating digital products, such as dense point clouds, digital surface models, and real orthophotos, by adjusting the internal and external orientation parameters, camera parameters, and removing distortions from the images. The Pix4D Mapper software was used to process the images taken in the two areas (Figure 4). When the photos taken by the UAV were uploaded to the software, they were displayed on a single project page. The photos were then processed using the software, resulting in the production of the desired data.

Figure 3. Ground control points of the study area.

Table 1. Coordinates of ground control points.

Point Number	x	y	z
1	497775,582	4621206,733	28,441
2	497853,537	4621325,441	28,450
3	498018,744	4621231,651	28,816
4	497938,142	4621077,287	28,472
5	498113,337	4620926,887	28,937
6	498136,556	4620976,928	28,736
7	498254,685	4620810,535	28,736
8	498275,678	4620827,063	28,486
9	498409,404	4620683,764	28,739
10	498492,582	4620603,182	28,413
11	498630,158	4620606,806	28,995
12	498512,888	4620539,809	28,533

The software automatically calculated the port numbers to be a minimum of 20,066, a maximum of 65,518, and an average of 38,069. In a single photograph, a minimum of 266 and a maximum of 43,740 pairs were identified, with an average of 16,380 pairs. The number of 3D points created from the connection points ranged from a minimum of 1 on 38 photographs to a maximum of 791,230 on 2 photographs (Figure 5).

After creating the point clouds, the next step was to mark the ground control points. This involved calling the control points from a file, opening them in the program, and defining all points in the point cloud so that each control point was marked on at least 3 photographs. This process resulted in the conversion (external orientation) between the photograph and the object coordinate system through the program (Figure 6).

The final product of the points processed in the software is the true orthophoto, also known as an orthomosaic in the program. These images are free from geometric and perspective distortions and have had camera errors eliminated. They can be used as maps and provide coordinate information with the required sensitivities. Camera perspective distortions are corrected by using a digital surface model (Figure 7)

Figure 4. Displaying images in Pix4D Mapper software.

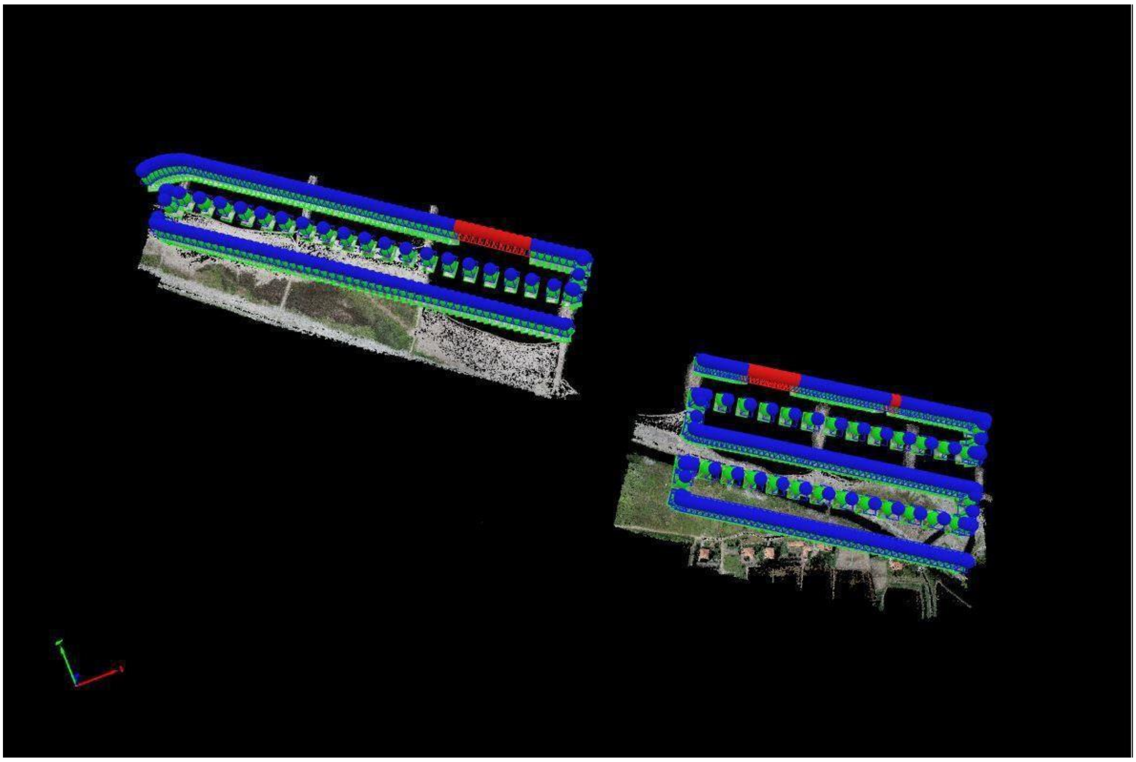

Figure 5. 3D sparse point cloud display with photo locations.

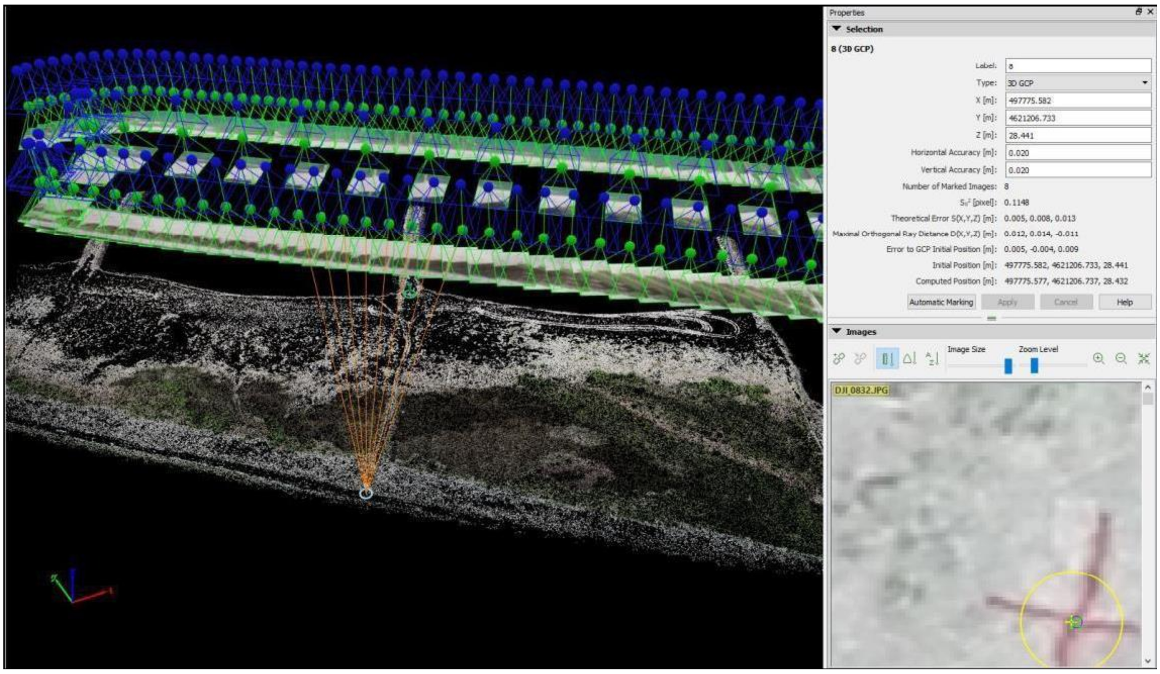

Figure 6. Processing of ground control points in images.

Figure 7. Production of true orthophotos in Pix4D Mapper software.

3. Result

As a result of the photo evaluation of the captured images with Pix4D Mapper software, 370 out of 398 photos were used to produce a 3D textured model, digital surface model, and real orthophoto in an area of 0.314 km2. The resulting data had a precision of 2.57 GSD (area represented in a pixel). The 12 GCPs used in the study were processed with 0.007 m precision. The balancing process resulted in the production of 1,618,538 points, and point concentration produced 108,764,252 3D points. The match rates were desirable, with 37,535 ports per image and 14,759.8 dots per rendered image.

In the camera optimization phase, the rate reached 7.79% at the threshold of 5%. It took 6 hours 36 minutes to create a dense point cloud, 29 minutes to create a textured 3D mesh model, 46 minutes to create a digital elevation model (DEM), and 43 minutes to create a true orthophoto, for a total processing time of approximately 8 hours and 30 minutes.

Spurs numbered 1, 2, and 3 were constructed by teams from the Bafra Plain Irrigation Project Directorate affiliated with the DSI VII Regional Directorate due to the coastal regression of the Belt Canal, built in 1999, which caused the risk of sea water mixing with the canal water. Measurements have been regularly taken in the area where the spurs are located using classical terrestrial techniques since 2001. New spurs have been built in areas where coastal recession poses a risk.

In NetCAD 7.7 GIS software, the measurements taken by SHW and the shorelines between different years were used to determine the soil loss and coastal regression. Based on this data, a soil loss of 1213.2 $km2$ and 750 m inland regression were measured between 1988 and 2001. After the construction of spurs 4, 5, 6, 7, and 8 in 2003, 23105,783 $m2$ of soil was lost and 227.97 m of regression was measured between 2001 and 2004. Between 2004 and 2005, 123424,517 $m2$ of land was lost and the coastal regression was measured as 84.95 m, with a maximum decrease of 143.14 m to the east. In 2005-2007, there was a soil loss of 57342,326 $m2$ and a coastal recession of 87.80 m.

Spurs 9 and 10 were built in February 2008, and spurs 11 and 12 were built in September 2008. Spurs 13, 14, and 15 were completed in November 2009. Between 2007 and February 2008, when the last spurs were built, measurements indicated a soil loss of 69673,563 $m2$ and a coastal recession of 74.66 m. During the construction of the spurs, the coast continued to regress rapidly, with a coastal regression of 22.28 m between February and June 2008 and 18 m between June and September. Between September 2008 and November 2009, there was a coastal recession of 40 m and a seaward progress of 14 m due to grain accumulation between spurs 11 and 13. In 2009, a 128 m long stone fortification wall was built parallel to the sea next to spur 15. However, the four-ton stone wall was eventually eroded from the ground by the waves and submerged, showing that structures parallel to the sea cannot be a permanent measure against coastal erosion. Between 2009 and 2018, the last measurement period recorded by DSI, there was a coastal recession of 246.08 m and a soil loss of 317938,010 $m2$.

The coastline of 2019, obtained from the true orthophoto image, was compared with ground measurements made by DSI. The shoreline of 2019 was compared with the shoreline of 2007 between spurs 6 and 8, February 2008 between spurs 8 and 9, June 2008 between spurs 9 and 11, and November 2009 between spurs 11 and 13. The results of these detailed measurements made in NetCAD 7.7 software are presented in Table 2. Table 2 shows the soil loss and measured coastal regression in the area where coastal erosion occurred and the measured progress in the seaward direction where material accumulation was observed.

Table 2. Comparison of true orthophoto and terrestrial measurements.

Data	Spour Number	Costal Erosion	Material Accumulation
2007-2019	6-8	9,290 m^2	
February 2008-2019	8-9		8907,830 m^2
June 2008-2019	9-10		4773,075 m^2
June 2008-2019	10-11	266,084 m^2	244,195 m^2
November 2009-2019	11-12	393,547 m^2	255,455 m^2
November 2009-2019	12-13	875,430 m^2	

4. Discussion

The utilization of UAVs for coastal monitoring, as evidenced in our study, has underscored the technological advancements in the field of environmental science. This fusion of technology allows for a nuanced understanding of coastal dynamics over time, providing insights into both erosional and depositional features.

The efficacy of interventions aimed at mitigating coastal erosion, as seen in regions where artificial spurs have been implemented, carries important implications for coastal management strategies. Although these measures have been effective in stopping erosion, the increased movement observed in nearby areas indicates the necessity of a comprehensive approach to coastal defense tactics. The detailed comprehension facilitated by UAV surveillance helps to uncover both the advantages and potential disadvantages of physical actions, highlighting the significance of adaptive management solutions in coastal ecosystems.

While there are benefits to using UAVs for coastal surveillance, it is important to recognize their limitations. The difficulties in setting up control stations on loose terrain and the longer processing periods for bigger areas emphasize the logistical limitations of UAV applications. The existence of these restrictions emphasizes the necessity for ongoing technological progress and operational tactics to improve the efficiency and usefulness of UAVs in environmental monitoring.

5. Conclusion

This study investigated the utilization of Unmanned Aerial Vehicles (UAVs) for the purpose of measuring and monitoring coastal regions. The study's findings demonstrated that the orthophoto image generated by photogrammetric assessment utilizing UAVs exhibited comparable sensitivity and accuracy to measurements obtained through terrestrial approaches. The photogrammetric technique was used to compare the coastline with coasts from different years obtained using terrestrial techniques, enabling the identification of temporal changes.

Pix4D Mapper software effectively generated a 3D textured model, digital surface model, and accurate orthophoto of the research region. This data offers comprehensive information regarding the topography and characteristics of the region, which can be utilized for diverse objectives such as cartography, urban development, and examination.

The SHW VII Regional Directorate's actions to combat coastal erosion have been successful in halting erosion in locations where spurs were constructed, but also causing sediment accumulation and changes in sea currents in certain areas. The data generated by this technology can be used to monitor changes in vulnerable sections of coastal areas and precisely calculate the numerical values representing the level of risk. It is important to mention that the implementation of buildings like stone fortification walls has not demonstrated long-term effectiveness in addressing the issue of coastal erosion in the studied area. Continual monitoring and evaluation of various methods implemented to combat coastal erosion is crucial. It is necessary to explore a range of ways to identify the most efficient and sustainable solution.

An important benefit of utilizing UAVs for this objective is the simplicity and convenience in generating data. Utilizing photogrammetric software to analyze the acquired data and convert it into practical information enhances the method's comprehensibility and effectiveness. Moreover, the exceptional precision and accuracy of the data generated make the use of UAV approach more desirable in comparison to alternative methods.

Nevertheless, it is important to acknowledge that the utilization of UAVs does include certain constraints. In regions characterized by loose soil formations, determining and establishing control points might provide challenges. Furthermore, as the field's size expands, the duration for processing the data will also increase, necessitating sophisticated technology for storing and analyzing the captured photos.

Although there are restrictions, the utilization of UAVs for the measuring and monitoring of coastal areas provides substantial advantages in terms of rapidity, precision, and ease. The method's capacity to rapidly and effortlessly acquire precise data on coastal changes renders it a helpful instrument in addressing the hazards presented by coastal erosion.

Besides frequent utilization of Unmanned Aerial Vehicles (UAVs) to observe coastal areas for alterations caused by erosion or human activities such as the erection of spurs.

Apply the created data to wider applications such as urban planning, mapping, and environmental protection, guaranteeing that the gained insights are efficiently used in other disciplines.

Funding

The authors received no financial support for the research, authorship and/or publication of this article.

Author contributions

Erdem Emin Maraş: Conceptualization, Methodology, Validation, Writing-Reviewing, Editing.
Kübra Nur Karafazlı: Data curation, Writing-Original draft preparation, Software, Visualization, Investigation, Writing-Reviewing.

Conflicts of interest

All the authors of this paper have declared no conflicts of interest, either financial or personal, with any individuals or organizations that could potentially exert undue influence or introduce bias into the content of the paper. There are no conflicting interests or potential biases from other individuals or organizations that could unduly influence the content of the work.
The authors have stated that they have no potential conflicts of interest with the research, authorship, and/or publishing of this paper.

References

1. Konuk, N. (2018). Utilization and planning of coastal areas in Ordu Province, Turkey, Global NEST Journal, 20(1), 147-150. https://doi.org/10.30955/gnj.002363
2. Utomo, S. W., Risdianto, R. K., Tambunan, R. P., & Hernawan, U. (2021). Environmental sensitivity index analysis for coastal protection of oil spill in Fakfak, Papua, Indonesia. Global NEST Journal, 23(2), 241-248. https://doi.org/10.30955/gnj.003566
3. Sesli, F. A. (2006). Monitoring changes in coastal areas with digital photogrammetry. Journal of Geodesy, Geoinformation and Land Management, 95, 11-17.
4. Labuz, T. (2015). Environmental impacts-coastal erosion and coastline changes. In Second Assessment of Climate Change for the Baltic Sea Basin, 381–396. https://doi.org/10.1007/978-3-319-16006-1_20
5. Ventura, D., Bonifazi, A., Gravina, M. F., & Ardizzone, G. (2017). Unmanned aerial systems (UASs) for environmental monitoring: a review with applications in coastal habitats. Aerial Robots-Aerodynamics, Control and Applications, 165-184. https://doi.org/10.5772/intechopen.69598
6. Uzun, S. M., & Garipağaoğlu, N. (2014). Kıyı çizgisi değişiminin yaratacaği riskler açisindan İzmit Körfezi kıyılarının değerlendirilmesi. International Journal of Social Studies, 7(31).
7. Marghany, M. (2014). Simulation of three-dimesional of coastal erosion using differential interferometric synthetic aperture radar. Global NEST Journal, 16(1), 80-86. https://doi.org/10.30955/gnj.001055
8. Karadağ, A. A. (2012). Determination of the lower basin boundaries of Lake Kovada. Duzce University Journal of Forestry, 8(1), 58-76.
9. Şahin, K., & Bağcı, H. R. (2016). Evaluation of morphometric properties of major deltas with GIS and RS techniques. International Journal of Social Studies, 9(42), 984-990. https://doi.org/10.17719/jisr.20164216208
10. Thi, T., Trung, T., Oanh, P., Thang, D., & Nga, D. (2020). Impact of climate change on the environmental security of the Mekong River Delta Area. European Journal of Climate Change, 2, 11-21. https://doi.org/10.34154/2020-EJCC-0202-11-21/euraass
11. Yılmaz, C. (2005). Geographical analysis of coastal erosion in the Kızılırmak Delta. V. Turkish Quaternary Symposium, Istanbul Technical University Eurasian Geosciences Institute Publications, 227 – 234, İstanbul, Turkey.
12. Anlı, A., Polat, E., & Semiz, D. (2011). Analysis of Kırşehir Province drought and its effect on wetlands. 2. Turkey Wetlands Congress, Kırşehir, Turkey.
13. Ersoy, A., Turan, N., Arslan, H., & Kuleyin, A. (2021), Assessment of seawater intrusion in Kızılırmak Delta coastal area (North Turkey) using hydrochemical and isotopic data. Environmental Earth Sciences, 80, 400. https://doi.org/10.1007/s12665-021-09700-9
14. Ataol, M., Kale, M.M., & Tekkanat, İ.S. (2019). Assessment of the changes in shoreline using digital shoreline analysis system: a case study of Kızılırmak Delta in Northern Turkey from 1951 to 2017. Environmental Earth Sciences, 78, 1–9. https://doi.org/10.1007/s12665-019-8591-7
15. Özturk, D., Beyazit, I., & Kilic, F. (2015). Spatiotemporal analysis of shoreline changes of the Kizilirmak Delta. Journal of Coastal Research, 31 (6), 1389-1402. https://doi.org/10.2112/JCOASTRES-D-14-00159.1
16. Nazeer, M., Waqas, M., Shahzad, M. I., Zia, I., & Wu, W. (2020). Coastline vulnerability assessment through Landsat and Cubesats in a coastal mega city. Remote Sensing, 12, 749. https://doi.org/10.3390/rs12050749
17. Zeybek, H. İ., Uzun, A., Yılmaz, C., & Özdemir, S. (2011). Consequences of shoreline changes in the Kızılırmak Delta. Samsun Symposium 2, 885-896, Samsun, Turkey.
18. Bal, M., Oğuz, D., Bilir, M., Torun, Z., Sevil, Y., Yavuz, N., & Erciyas, Y. (2021). Take action for the Northern Lapwings: monitoring and awareness raising acitivities in Kizilirmak Delta, a Ramsar Site in Northern Turkey. International Wader Study Group Annual Conference.
19. Silwal, A., Tamang, S., & Adhikari, R. (2022). Use of unmanned aerial vehicle (UAV) for mapping, and accuracy assessment of the orthophoto with and without using GCPs: A case study in Nepal. Mersin Photogrammetry Journal, 4(2), 45-52. https://doi.org/10.53093/mephoj.1176847
20. Şenkal, E., Kaplan, G., & Avdan, U. (2021). Accuracy assessment of digital surface models from unmanned aerial vehicles' imagery on archaeological sites. International Journal of Engineering and Geosciences, 6(2), 81-89. https://doi.org/10.26833/ijeg.696001
21. Ishaand, B., & Adib, M. R. M. (2021). Shoreline monitoring using unmanned aerial vehicle (UAV) at Regency Beach, Port Dickson. In IOP Conference Series: Materials Science and Engineering 1144(1), 012060. IOP Publishing. https://doi.org/10.1088/1757-899X/1144/1/012060
22. Casella, E., Rovere, A., Pedroncini, A., Stark, C. P., Casella, M., Ferrari, M., & Firpo, M. (2016). Drones as tools for monitoring beach topography changes in the Ligurian Sea (NW Mediterranean). Geo-Marine Letters, 36, 151-163. https://doi.org/10.1007/s00367-016-0435-9
23. Chapapría, V. E., Peris, J. S., & González-Escrivá, J. A. (2022). Coastal monitoring using unmanned aerial vehicles (UAVs) for the management of the Spanish Mediterranean Coast: the case of Almenara-Sagunto. International Journal of Environmental Research and Public Health, 19(9), 5457. MDPI AG.

http://dx.doi.org/10.3390/ijerph19095457
24. Yang, Z., Yu, X., Dedman, S., Rosso, M., Zhu, J., Yang, J., Xia, Y., Tian, Y., Zhang, G., & Wang, J (2022). UAV remote sensing applications in marine monitoring: knowledge visualization and review. Science of The Total Environment, 838, 155939. https://doi.org/10.1016/j.scitotenv.2022.155939.
25. Papaknstantinou, A., Topouzelis, K., & Pavlogeorgatos, G. (2016) Coastline zones identification and 3D coastal mapping using UAV spatial data. International Journal of Geo-Information, 5(6),75. https://doi.org/10.3390/ijgi5060075
26. Kokeza, Z., Vujasinović, M., Govedarica, M., Milojević, B., & Jakovljević, G. (2020). Automatic building footprint extraction from UAV images using neural networks. Geodetski vestnik, 64 (4), 545-561. https://doi.org/10.15292/geodetski-vestnik.2020.04.545-561
27. Yoo, C. I., & Oh, T. S. (2016). Beach volume change using UAV photogrammetry Songjung Beach, Korea. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 41, 1201-1205. https://doi.org/10.5194/isprsarchives-XLI-B8-1201-2016
28. Mancini, F., Dubbini, M., Gattelli, M., Stecchi, F., Fabbri, S., & Gabbianelli, G. (2013). Using unmanned aerial vehicles (UAV) for high-resolution reconstruction of topography: the structure from motion approach on coastal environments. Remote Sensing, 5(12), 6880-6898. https://doi.org/10.3390/rs5126880
29. Laporte-Fauret, Q., Marieu, V., Castelle, B., Michalet, R., Bujan, S., & Rosebery, D. (2019). Low- cost UAV for high-resolution and large-scale coastal dune change monitoring using photogrammetry. Journal of Marine Science and Engineering, 7(3), 63. https://doi.org/10.3390/jmse7030063
30. Flener, C., Vaaja, M., Jaakkola, A., Krooks, A., Kaartinen, H., Kukko, A., Kasvi, E., Hyyppä, H., Hyyppä, J., Alho, P. (2013). Seamless mapping of river channels at high resolution using mobile LiDAR and UAV-photography. Remote Sensing, 5(12), 6382-6407. https://doi.org/10.3390/rs5126382
31. Hugenholtz, C. H., Levin, N., Barchyn, T. E., & Baddock, M. C. (2012). Remote sensing and spatial analysis of aeolian sand dunes: a review and outlook. Earth-science reviews, 111(3-4), 319-334. https://doi.org 10.1016/j.earscirev.2011.11.006
32. Ozturk, D., & Sesli, F. A. (2015). Shoreline change analysis of the Kizilirmak Lagoon Series. Ocean & Coastal Management, 118, 290-308. https://doi.org/10.1016/j.ocecoaman.2015.03.009
33. Maraş, E. E., & Nasery, N. (2023). Investigating the length, area and volume measurement accuracy of UAV-Based oblique photogrammetry models produced with and without ground control points. International Journal of Engineering and Geosciences, 8(1), 32-51. https://doi.org/10.26833/ijeg.1017176