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Original article

Coastal Erosion and Sedimentation in Khums City, Libya using Sentinel-1A Technology: An Environmental Study

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Abstract
The majority of coastal regions worldwide are currently experiencing erosion processes, which are frequently brought on by modifications in the sediment balance brought on by both natural and man-made sources. Numerous Mediterranean locations, including the study area, are affected by this problem. The coastal area's erosion and sedimentation rates are not constant, and the pace of change is not uniform and varies widely, according to this study. Using Sentinal-1A remotely sensed satellite data sets, the study examined coastline changes from 2000 to 2021 and found such disparities in shoreline changes throughout the previous 21 years. The rates of erosion and accumulation were also calculated. Using many profiles, each of which expressed a rate of coastal erosion or sedimentation, the Digital coastline Analysis System (DSAS) tool was utilized to determine patterns in coastline change. According to the findings, the research site's west had a high rate of erosion, while its east had a high rate of sedimentation. In the center Khums area, both rates were equal. According to the results, sedimentation rates were higher than those of the study areas, with the exception of Basis Island, where erosion rates were higher. The rates calculated in this study and the classification of the study site's beaches may be very helpful in determining the cumulative impact and erosion risks of the coastal areas under study, as well as in developing sustainable development plans for them and raising awareness in the most vulnerable areas.
Keywords: DSAS, Sentinal-A1, Khums, Libya.

Introduction

The loss or displacement of land along the coast due to the interplay of beaches, waves, and oceans—often in conjunction with the impact of human activity—is known as coastal erosion. Sand and sediments are moved from the shoreline by wind, waves, tides, long shore currents, surface water runoff, or groundwater intrusion. This process is known as coastal erosion [1].

According to a study conducted by Kieran Westley [2] utilizing satellite imagery, rising coastal erosion poses a threat to the preservation or destruction of archaeological monuments along the Libyan coastline. Rising coastal erosion is a hazard to the maintenance or destruction of archaeological structures throughout the Libyan coastline, as per research by Kieran Westley using satellite photography. Importantly, the investigation confirmed that the ancient Libyan ports of Tocra (ancient Tokhira), Susa (ancient Apollonia), and Ptolemais (ancient Ptolemy) were all severely eroded by the sea. Based on the study's findings, erosion has been particularly high and rapid over the last decade. Rising sea levels due to climate change are likely to make the problem worse in the coming years, and the situation could get even worse if the rate of sea level rise accelerates, which is predicted to happen if emissions of greenhouse gases continue to climb. The erosion process has a substantial influence on the Libyan shore, and the author and her research team emphasized that this damage could only worsen in the near future.

Martin Heger [3] also used satellite images to report on the effects of coastal erosion in North African countries, including Libya. They found that Morocco's coasts are the second most eroded coastal areas in the world, after South Asia, where parts of Bangladesh are rapidly disappearing. The annual rate of erosion was 0.70 meters. According to the survey, Tunisia's average annual coastal erosion rate was 0.50 meters, while Libya's average yearly rate was over 0.30 meters. It clarified that certain regions referred to as "hot spots" are vanishing at a rate of up to several meters annually.

For instance, it predicted that half of the beaches in the Tunisian coast's cities of Djerba, Hammamet, and Soliman would truly vanish. According to the research, the World Bank's executives attempted to estimate the losses by calculating the worth of the infrastructure and lands lost along the surveyed coasts. They discovered that it is equivalent to 0.7% in Libya, or more than a quarter of a billion dollars a year. According to Ahmad Emrage & Julia Nikolaus [4], Libya's coastal flood risk is rated as high, which means that at least one devastating wave is anticipated to flood the shore during the next ten years.

Based on this information, every human activity along the coast should have the effects of coastal flooding taken into account at various project stages. The degree of coastal flood danger should be taken into consideration when making decisions on project planning, design, and building techniques. To fully account for the level of risk, more specific information should be gathered. Seasonal floods in Libya are common and have little effect, according to a different study by El-Mohajr [5]. However, because of the increased frequency

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of floods brought on by rainstorms in the Mediterranean as a result of extreme weather events linked to climate change, floods have become more common and significant in recent decades. Urban encroachment on agricultural lands and the growing population density in cities have made this situation worse in recent years. More than 26 major floods occurred between 1961 and 2010, according to flood records, and there have also been four floods in the recent ten years, in 2014, 2018, 2019, and 2023.
Libya's coastal erosion is greatly impacted by all of this. The study region exhibits a number of indicators of coastal erosion issues. Satellite imagery revealed that parts of the targeted coastline are deeper than others and have rocks devoid of beach sand, which explains the gradual erosion process. The research area has muddy currents near its coastlines in a unique fashion throughout the seasons, which explains why the shoreline erodes over extended periods of time when these currents are present. International studies indicate that beach erosion happens when severe rains cause valleys to flood. This hydrological process is normal and causes the coastline's topography to alter, which in turn causes erosion. The coastline is vulnerable to simple erosion due to tidal operations, valley erosion, and severe rains. In several study areas, soil erosion activities were recorded close to the beaches for commercial purposes or tourism expansions. By identifying the precise locations and rates of the most severe erosion, this study seeks to assess the extent of coastal erosion in the study area, and make clear how close this erosion is to cities or other places where people have been active, and how human activity affects the study region as well.

Methods

Study location

The study's focus is khums city, which is situated on Libya western coast. It lies between latitudes 33 degrees east and longitudes 15 degrees north, according to figure (1), the study coast is 58.76 km long, extending from wadi kaam in the east to wadi besis in the west.

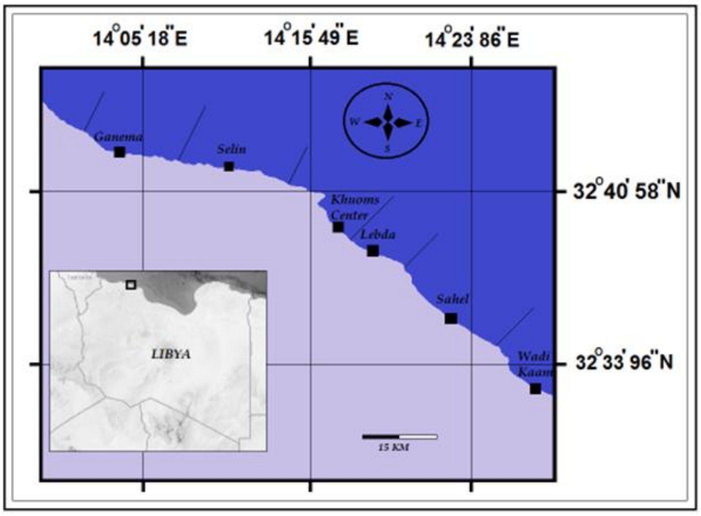

Figure 1. Study location

As illustrated in figure (2), the region is distinguished by its high topography in the west and south and its decreasing terrain as we move east and north. This influences the amount of sediment brought to the beaches and its relationship to the processes of sedimentation and erosion on the coast as well as the amount of rainfall. In addition to summer resorts in the east and west and Roman ruins at leptis magna and qaser selin, which are impacted by coastal erosion each year, the population core is located around the city center's beaches. Its coasts are home to a commercial port and a power generation station, which contribute to the erosion of the surrounding beaches in some places and the sedimentation of the coast in others.
In addition to the sedimentation and accumulation processes brought about by the large valleys, the climate is Mediterranean, with rain falling in the winter, tides appearing on the beaches, and strong waves during this season. In the summer, when ebb and flow occur and evaporation increases, the sedimentation and accumulation processes are minimal. The research area's coastline has very little vegetation cover, with just a few, sporadic pine and palm trees. The esparto plant, along with other thorny and herbaceous plants that grow on the rocks close to the beaches, is the dominant plant.

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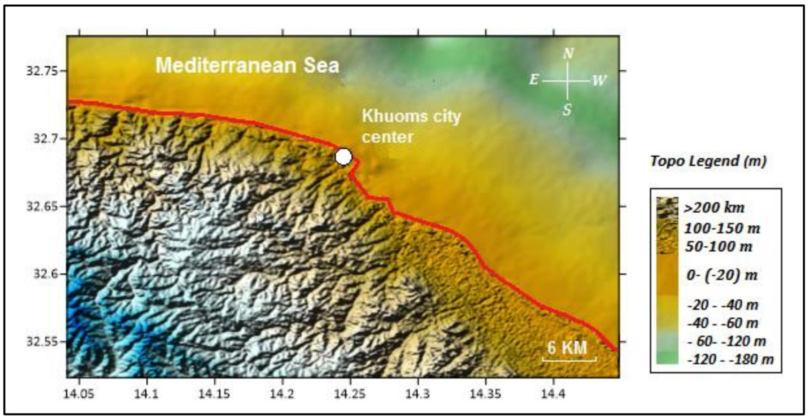

Figure 2. Topography of the study area and coastline in red.

Since every area of the study coast has a different topography, it was easier to identify the erosion and sedimentation spots in each of the six coastal sections. The Selin coast was the longest, followed by the ghanima coast and the Sahel shore. According to Table (1), the coasts of the wadi kaam, lebda, and khums center regions were all comparable, with the lebda shoreline being the smallest.

Table 1. Study coastal areas

Target coast name	Coast length in km	Location
Khuoms city center	6.15	From Sebiadja beach in the east to the port in the west
Selin	18.74	Between the naval base in the east and the Naqaza region in the west
Ganema	9.30	From Basis Island in the west to the Ghanima region's Gulf of Qaws in the east
Lebda	6.05	From Farwa Resort in the West to the Desalination Plant in the East
Sahel	8.12	From the desalination station in the west to the Al-Nazla beach in the east
Wadi Kaam	6.23	From Al-Tuwaibiyah Beach in the west to Wadi Kaam in the east

Data collection

Sentinal-1A satellite data, specifically those from 2000 to 2021, were used in this study. Because of its orbital height, which removes distortion errors in the imaging angles at the satellite's orbital levels, the data from this satellite were used.

In order to gather precise and unambiguous data regarding the rates of coastal erosion and sedimentation in the research areas over an extended period of time, the study period was selected based on the availability of official data sources for the satellite and its time series within annual periods.

Data analysis

A program for assessing the digital coastline system, which graphically analyzes satellite images and computes the change in the coastline over time, was also utilized in this study to determine the change in coastal boundaries. The sixth version, DSAS v.6, will be employed in this study [6]. The data of the rate of sedimentation and coastal erosion in several coastal sites worldwide were computed using it. It offers an automated technique to divide the coastline into parts with varying depths of measurement, yielding accurate and dependable findings regarding the degree of coastal erosion and its history. It illustrates the magnitude of current erosion as well as the trends of coastal erosion throughout time. Additionally, it offers statistical information for every area in the form of precise graphic curves.The way this program operates is shown in figure (3), where the targeted coastline is divided into multiple sections (a, b, c, and d). The length of the coastline for each section is indicated by lines at perpendicular angles that fall on the line. The following formula is then used to calculate it [6];

$d=s\times t$

Where:

d = eroded distance from baseline.

s = changes in slope value.

t = coastline history.

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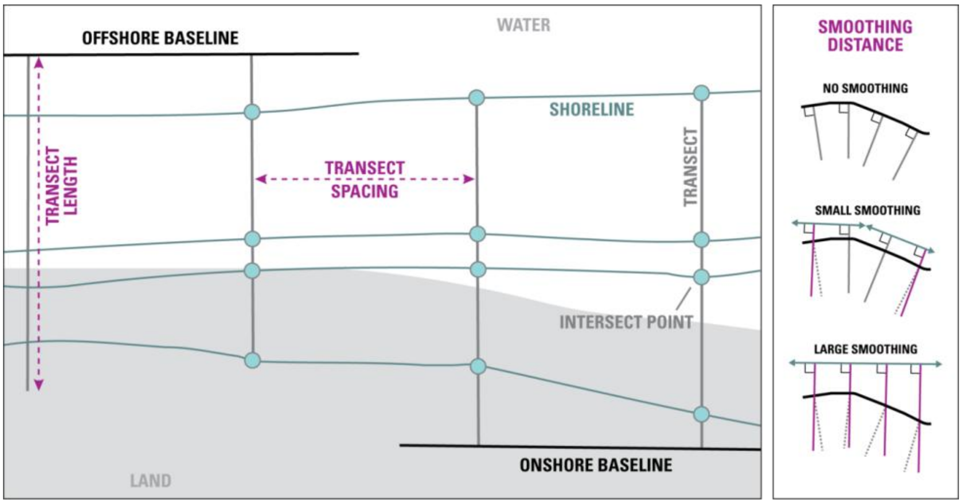

Figure 3. Diagram illustrating the operation of the DSAS algorithm, which divides the target shoreline into sections and evaluates each section's level of displacement [6].

Results and discussion

The khums center coast had the highest erosion rate (-14.78 meters), while the lebda coast had the lowest rate (-0.02 meters). The sahel coast had the highest sedimentation rate (28.82 meters), followed by the Wadi Kaam coast (25.64 meters), and the ganema coast had the lowest sedimentation rate (0.24), followed by the lebda coast (0.38 meters), according to Table (2).

According to this study, the coasts of the besis Island were often subjected to significant rates of erosion; yet, no sedimentation rates were observed during the study period, suggesting that the erosion was gradual. This is because, while sedimentation rates rise in areas where valleys are dispersed and rich in high sediments near their coastlines, erosion rates rise in areas with rocky coastal hilly terrain and in touch with deep waves. In contrast, the coastal region, which was distinguished by the lack of rough hilly terrain, saw weaker rates of erosion and higher rates of sedimentation.

Although the topography of the ghanema coast was comparable to that of the selin coasts, the beaches there saw a larger tidal current than those found on the selin coast, which resulted in higher rates of sedimentation than erosion. Coastal currents from the west generally caused more disruption to the selin and ghanema coasts [7]. On the wadi kaam coast, erosion rates were noted on the east and west beaches of the bays close to the valley, although sediment rates were higher and recorded at the well-known valley.

Table 2. Annual results of erosion and sediment rates into study sections

Year	Ghanema	Besis Island	Selin	City Center	Lebda	Sahel	Wadi Kaam
2000	6.67	-5.12	1.62	-14.78	6.06	28.82	25.64
2001	3.6	-8.31	2.99	-12.81	4.37	23.98	22.21
2002	2.66	-6.95	6.57	-10.19	4.36	16.09	23.31
2003	2.98	-4.76	10.59	-5.19	10.61	13.37	18.81
2004	0.63	-6.42	13.09	-10.42	3.5	14.04	17.05
2005	7	-3.8	7.92	-11.18	2.05	18.27	15.74
2006	7.53	-0.08	9.29	0.39	13.51	14.31	16.22
2007	3.66	-6.88	8.74	-5.06	16.93	22.08	24.06
2008	7.27	-3.47	6.24	-13.97	14.15	22.48	16.51
2009	5.71	-8.43	-1.19	-10.61	11.72	16.82	15.3
2010	3.65	-3.19	10.53	-9.08	3.64	14.2	2.67
2011	1.99	-3.81	11.86	9.54	0.38	8.78	3.28
2012	-0.28	-3.38	-2.01	13.58	-0.02	7.35	-0.89
2013	-2.36	-2.75	-5.7	15.82	-0.18	-1.16	8.57
2014	0.88	-0.55	1.83	15.96	3.51	6.21	6.45
2015	-3.34	-2.12	-4.1	23.1	-6.68	-2.47	-3.95
2016	-1.08	-1.95	1.33	18.83	-1.45	2.51	5.08
2017	0.77	-3.75	7.9	16.91	2.05	-2.74	6.97
2018	-3.15	-1.27	-2.01	7.16	-7.28	4.19	-9.65
2019	-0.75	1.5	-8.64	22.27	-7.5	-5.59	-7.9
2020	0.24	0	-2.63	14.93	-10.92	-1.2	-3.89
2021	-0.86	-0.5	-0.51	19.5	-1.28	2.35	0.67

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Erosion rates (negative values) and sedimentation rates (positive values) are displayed in the time series for the study sections in the following figures curve (4), which shows that deposition was in 16 sections and erosion in six, shows that the sedimentation rate decreased from 2000 (up to 25 meters) until 2006, then increased in 2007, then decreased in 2008 until 2012, and finally fluctuated between erosion and sedimentation rates from 2013 to 2017.and the erosion rate in the Ganema area reached its maximum in 2018 (-10) meters.
The time series for Besis Island on ghanema coast, shown in figure (5), revealed that it has 21 segments that reflect erosion rates for every year of the research, with the exception of 2019, when there was only one segment that represented the sedimentation rate. 2009 saw the highest rate of erosion, while 2006 saw the lowest. Erosion rates generally peaked between 2000 and 2010 before declining until 2021, the study's last year.

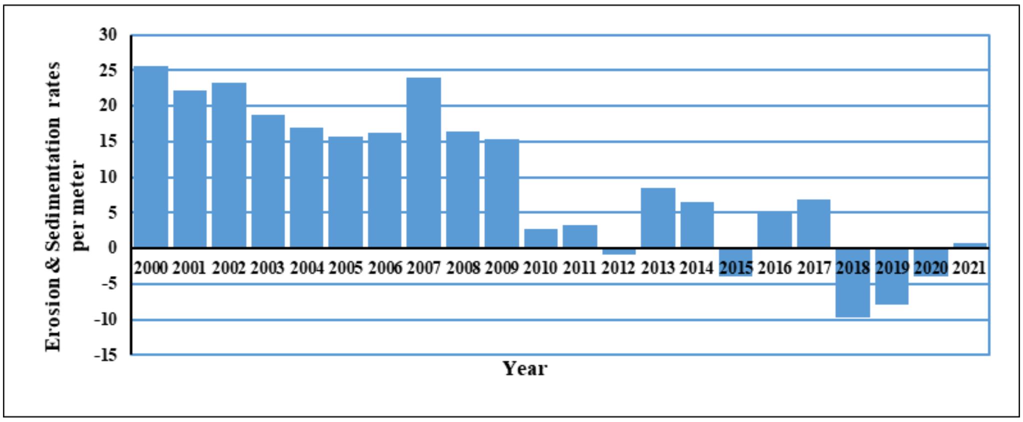

Figure 4. Time series of Ghanema area

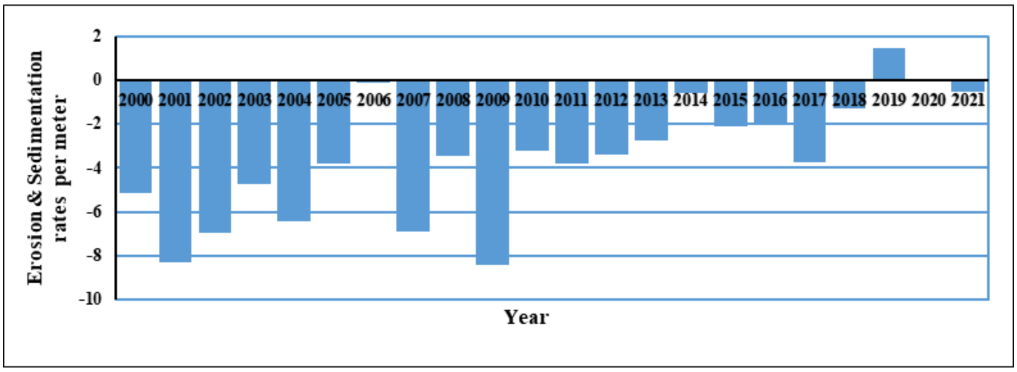

Figure 5. Time series of Besis Island, Ghanema District

Eight erosion and fourteen sedimentations transect are shown in figure (6) for the selin coast. Sediment rates rose between 2000 and 2004, then fell until 2009, then rose once more until 2011, after 2012, sediment rates started to decline, while erosion rates rose until 2021.

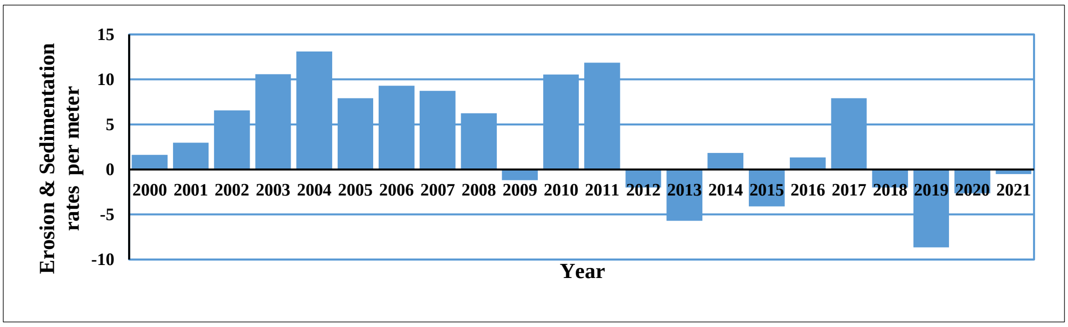

Figure 6. Time series of Selin region

Eleven erosion sections and eleven sedimentation sections were found on the coast of khums' city center. This suggests that this is the only place in the study where the effects of erosion and sedimentation were equal. Since sedimentation rates increased after 2011, it is evident from figure (7) that 2011 was the year that the effects of erosion and sedimentation were separated, satellite data showed that the harbor and marina were erosion areas, whereas resorts were deposition sites.

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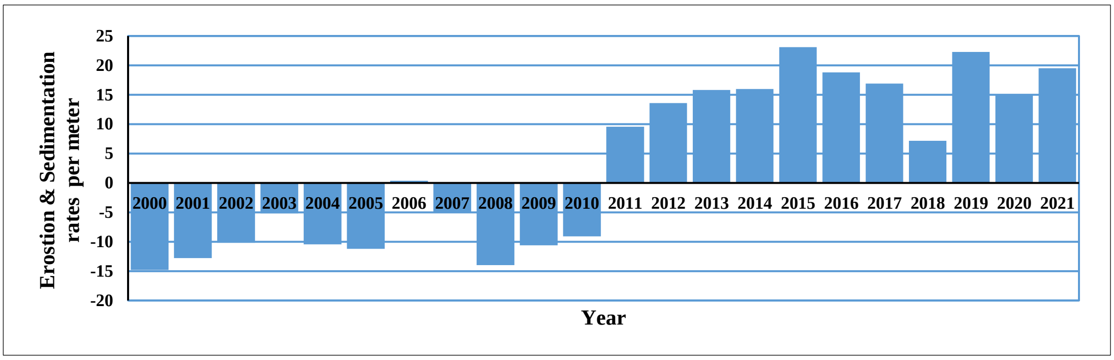

Figure 7. Time series of Khums city center

For the lebda coast, figure (8) shows that there were six erosion transects and sixteen sedimentation transects. The erosion rates were recorded between 2015 and the conclusion of the study period, based on satellite data, the erosion transects extended up to the gas desalination facility and encompassed the lebda grand monuments.

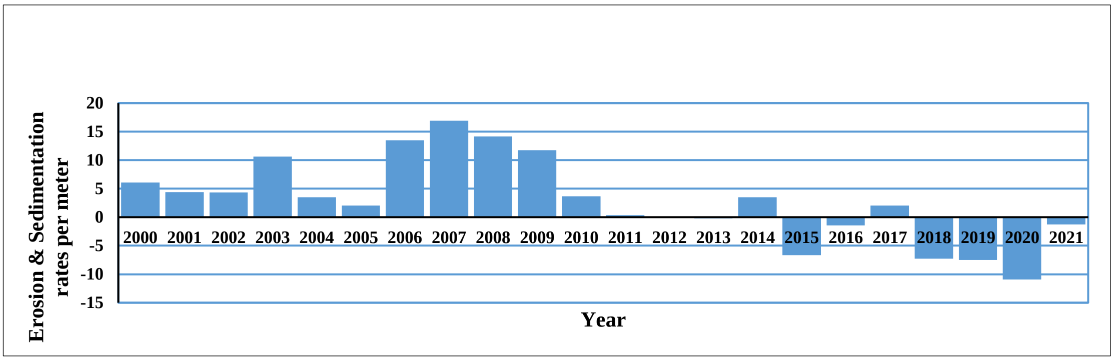

Figure 8. Time series of Lebda section

During the study period, there were five erosion profiles and seventeen sedimentation profiles, which were determined to be prevalent in the sahel zone (Figure 9), this can be explained by the flat, non-mountainous landscape of the area, which aids in the processes of while erosion was minimal in comparison to the other research sites, deposition was focused in the coves in the eastern part of the region.

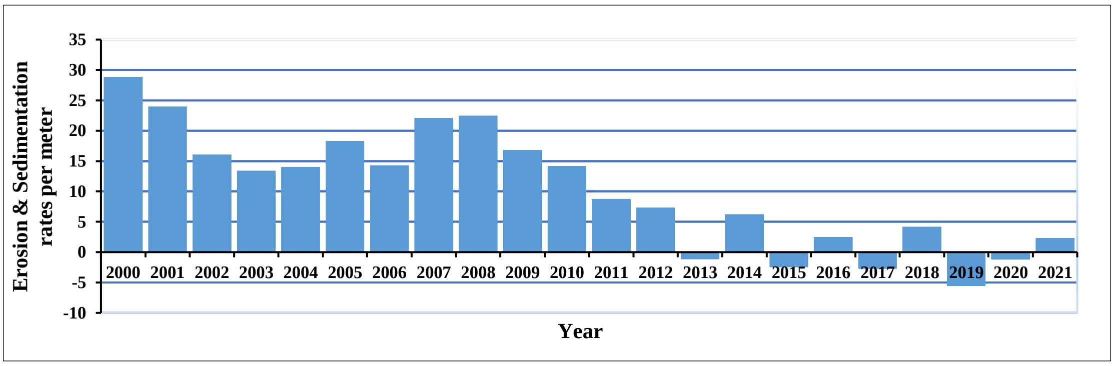

Figure 9. Time series of Sahel area

High sedimentation rates comparable to those at the Sahel site, where 17 sedimentation transects predominated among the four erosion transects, were seen at the wadi kaam site, as illustrated in figure 10, there were 17 sedimentation portions that outnumbered the four erosion parts; the valley site had the highest sedimentation rates, followed by west valley bay. The most significant erosion rates seen in this image have been present since 2018, which helps to explain the valley's dry episodes, which lasted until the study's final year.

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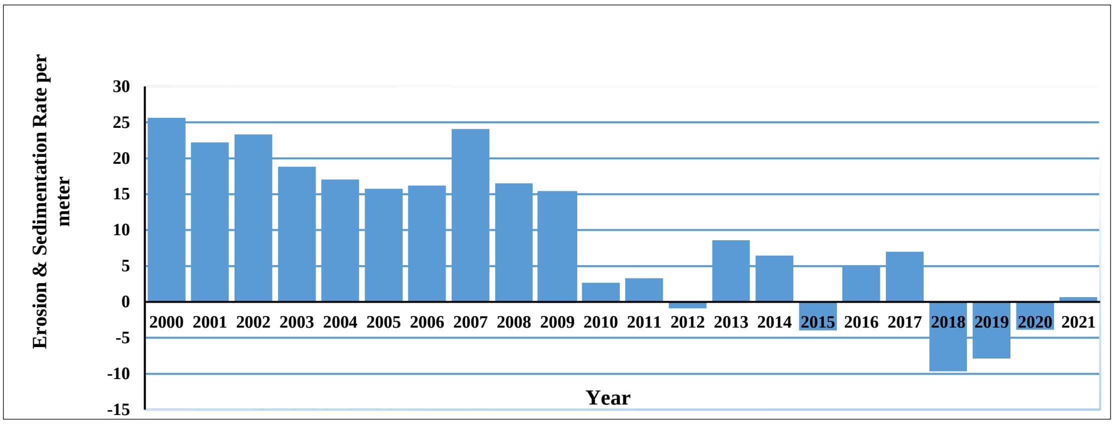

Figure 10. Time series of Wadi Kaam site

Conclusion

The DSAS program played a role in illustrating the erosion and deposition lines for each year, which were converted into rates based on the algorithm used. This study proved the value of Sentinal-1A satellite data, which helped in obtaining accurate data of erosion and deposition rates in the study area. While deposition rates were higher in the western parts of the study site, where the terrain is flat and known to be rugged, erosion rates were more prevalent in the eastern part of the study area, where the terrain is rugged in both areas, the area is flat and known as wadi kaam, a wide valley with large sedimentary deposits over time. Research coastal erosion rates have increased due to a combination of human activities, rugged terrain and poor vegetation cover.

Conflict of interest. Nil

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المستخلص

تشهد غالبية المناطق الساحلية في جميع أنحاء العالم حاليًا عمليات تآكل، والتي تحدث غالبًا بسبب التعديلات في توازن الرواسب الناجمة عن مصادر طبيعية وبشرية. تتأثر العديد من المواقع المتوسطية، بما في ذلك منطقة الدراسة، بهذه المشكلة. وفقًا لهذه الدراسة، فإن معدلات التآكل والترسيب في المنطقة الساحلية ليست ثابتة، ووتيرة التغيير ليست موحدة وتختلف على نطاق واسع. باستخدام مجموعات بيانات الأقمار الصناعية المستشعرة عن بعد، فحصت الدراسة تغييرات الخط الساحلي من عام 2000 إلى عام 2021 ووجدت مثل هذه التفاوتات في تغييرات الخط الساحلي طوال السنوات ال 21 السابقة. كما تم حساب معدلات التآكل والتراكم. باستخدام العديد من الملفات الشخصية، والتي يعبر كل منها عن معدل تآكل أو ترسيب الساحل، تم استخدام أداة نظام تحليل الخط الساحلي الرقمي لتحديد أنماط تغير الخط الساحلي. وفقًا للنتائج، كان غرب موقع البحث لديه معدل تآكل مرتفع، بينما كان شرقه لديه معدل ترسيب مرتفع. وفي منطقة الخمس الوسطى كانت النسبتان متساويتين، ووفقاً للنتائج فإن نسب الترسيب كانت أعلى من نسب مناطق الدراسة باستثناء جزيرة باسيس حيث كانت نسب التعرية أعلى، وقد تكون النسب المحسوبة في هذه الدراسة وتصنيف شواطئ موقع الدراسة مفيدة جداً في تحديد الأثر التراكمي ومخاطر التعرية للمناطق الساحلية قيد الدراسة، وكذلك في وضع خطط التنمية المستدامة لها ورفع الوعي في المناطق الأكثر عرضة للخطر.

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