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Geomorphology of Janan Island on the Northwest Coast of Qatar State

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Abstract

Janan Island is one of the uninhabited, flat-surfaced rocky islands that is located in the waters of the Gulf of Salwa to the west of the northwest coast of the State of Qatar, about 6 km away, extending from the northwest towards the southeast with the direction of the prevailing northwest winds. The study of the island aims to determine its natural, morphological, and topographical characteristics, study the most important landforms therein, and draw a geomorphological and bathymetric map of the island. The island is distinguished by its small area of 0.16 km2 and its low isolation index from Qatari land, which amounts to 2.5, which indicates the severity of its proximity to the mainland. The surrounding waters are characterized by their shallowness, coral reefs spread across its coasts, and many geomorphological landforms such as sea cliffs, shore platforms, sandy spits, headlands and bays, Sabkhas, caves, and sea stacks, which qualify it to be a destination for tourists with the aim of camping, tranquility, recreation, and the practice of diving and hunting.

Keywords: Janan Island, Qatar, form factor, sandy spit, cliffs, stacks.

1. Introduction

Janan Island, with an area of less than one square kilometer, is one of the small-uninhabited islands scattered along the northwest coast of the State of Qatar. This description matches Patrick Nunn's definition of small islands (Nunn, 1987, p. 228).

Despite the small area of Janan Island, it contains natural capabilities that qualify it for future development, such as various geomorphological landforms such as sandy and rocky beaches, sea steaks, pits, sand spits, beaches, coastal marshes, and others. The small area of Janan Island is important for the study of its geomorphology due to the simplicity of the factors that have made it easier to develop its landforms than any other area on the mainland with such a small area (Nunn, 1987, p. 227). In

addition to the possibility of discovering natural gas or oil in the surrounding waters, which adds great importance to its study.

Weathering features appear on Janan Island's landforms, and various types of weathering processes are active as a result of the interaction of the rocks that make up the island's coasts with various climate elements. The island has also been subjected to numerous marine geomorphological processes, which have contributed to the formation of numerous geomorphological forms on it.

The researcher encountered a scarcity of previous studies that discuss the island of Janan, with the exception of mentioning the name of the island of Janan in some studies that discussed the Qatari-Bahraini dispute, a portion of which revolved around the ownership of the island, which ended with the International Court of Justice ruling in 2001 that the State of Qatar has the right to its sovereignty over the island of Janan (I.C.J, 2001; Jassim Karam, 2002; Barbara Kwiatkowski, 2002; Majeed Shehab, 2009; Krista E. Wiegand, 2012; Anaam Shaheen, 2019). The lack of studies on the island may be due to a number of factors, including its small size and shallow waters full of algae that separate it from the Qatari mainland, its harsh climate represented by high temperatures and atmospheric humidity, and the island's lack of fresh water sources, no researcher has undertaken to study it (Mohammed , Al-Rashed, & Al-Anzan, 2007, p. 13).

Because the geomorphology of Janan Island has not been studied, despite its importance to the State of Qatar, the current study aims to study its natural, spatial, and morphological characteristics, as well as the geomorphological landforms scattered throughout it, draw a geomorphological map of the island, and present some proposals to maximize the island's benefits. The detailed geomorphological study of the island aids in the analysis of the relationship between geomorphological forms and their evolution; it also provides preliminary scientific material for researchers from various disciplines to provide future detailed studies on the island.

2. Study Area

Janan Island is situated in the middle of the Qatar Peninsula's western coast, at the intersection of latitude 25° 33' 30.37" N and longitude 50° 44' 7.81" E. It is surrounded by the warm Salwa Bay waters (Fig. 1). Janan Island, to the east and southeast, borders Qatari territory. It is approximately 8.5 km to the east of the Abrouq Peninsula and approximately 6 km to the southeast of Ras Dukhan. It is bounded on the west by a depth line of -5 meters, and on the north by the Bahraini Hawar Islands, which are only 2.9 km away. The island's area is approximately 0.11 km2, and it extends from the northwest at 312° to the southeast at 133°, with a length of approximately 0.8 km and an

average width of approximately 0.12 km. The shallowness of the surrounding waters, the calmness of its waters, and the distinctive winding coasts that contain many geomorphological forms characterize the island, which encourages development and prepares it for visitors to enjoy its interesting natural scenery. Despite the availability of these natural ingredients, the island remains uninhabited, and its small size could be one of the reasons for this (Fig. 1, 2).

Figure 1. The location of Janan's Island

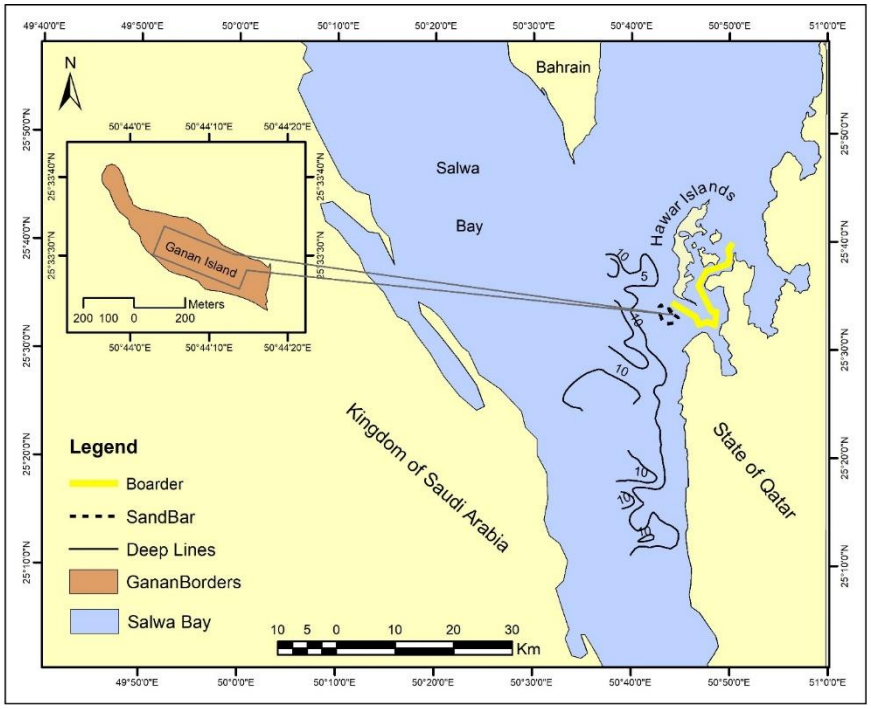


Figure 2

Figure 2. Shows the general view of Janan Island from the eastern coast and notes the shallowness of the water that surrounds the island, the coral reefs that appear in dark color, the sandy beach, and the natural vegetation that grows above the surface of the island.

Janan Island is a sensitive natural environment with many halophytic plants like Tetraena qatarensis, Aeluropus lagopoides, and Limonium axillare (Ministry of Municipality and Environment, 2021), as well as some different types of fish and marine animals like dugongs, and it is a popular destination for many migratory and resident birds. Seagulls, herons, Phalacrocorax nigrogularis, and other birds use the island for nesting and resting. Janan's island is known as the island of birds (Diwan, 2022, p. 87). (Figure 3).

Figure 3. A bird rests on its nest on Janan Island.

The strategic significance of Janan Island stems from its geographical extension of Qatari land and its inclusion in the Qatari-Bahraini ownership dispute, which lasted for ten years in the International Court of Justice due to its proximity to the Bahraini Hawar Islands. Its proximity to the maritime border line separating Qatar and Bahrain, which is only 1.2 kilometers away, has increased its significance, as Janan Island is located within the innocent sea passage path in Bahraini territorial waters, and it was previously used as a resting place for pearl fishermen in the region.

Janan Island is a rocky island consisting of limestone rocks and loose sediments ranging in age from Tertiary to Quaternary. The Upper Dammam Formation, known as the Simaisma Formation, which belongs to the Middle Eocene, covers most of Janan Island. The Upper Dammam formation is divided into two members: Janan member at the bottom, whose name is derived from the island of Janan, the subject of the current study, and consists of limestone and dolomite, and the Salwa member at the top, which consists of dolomitic limestone mixed with

lime clay (marl) (Leblanc, 2015, pp. 667-668). The Simaisma limestone formation is characterized by the presence of remains of marine animals from the Velates, the transparency of its rocks, and the abundance of its fragments (Ziab, 2001, p. 122). The Upper Dammam formations indicate that the sedimentation environment was shallow marine (LeBlanc, 2008, p. 15).

The Dammam formations on the island of Janan are made up of limestone, dolomite, marl, chalk, clay, and gypsum, as well as the presence of some fossils such as Bivalves and Nummulites (Harald et al., 2003; Al Saad et al. 2002; Embabi & Ali., 1990; Jacques LeBlanc, 2022), and it has some irregular cracks in it. The Upper Dammam formations are characterized by their weakness and lack of resistance to erosion processes in general, and then the characteristics of their soluble and sculptural limestone rocks contributed to the formation of many landforms of marine erosion such as shore platforms, dissolution holes, etc., and the exchange of limestone and marl led to the prevalence of undermining and rock falls. which leads to the retreat of the cliffs of the island and then provides beach sediments that are washed away by the wave current back to the sea, as it represents one of the sources of sediment on the island.

As for the formations of the Quaternary age spread on the island, they consist of coastal marine sediments, calcareous sands, Sabkha deposits, consisting of loose sand, remnants of shells, quartz atoms, and continental sediments that include gravel sediments, Celtic mud sediments, and Aeolian sand sediments. These sediments are distinguished by their disintegration, their lack of resistance to erosion, their ease of transport over the island, and the formation of some landforms of marine sedimentation such as sand spits and sandy beaches.

Janan Island's climate is distinguished by moderate temperatures, a tendency toward warmth, and a lack of rain in the winter, and high temperatures, humidity, and dryness in the summer. The annual average temperature ranges from 22.2°C to 43.1°C, and temperatures can reach record levels. The average annual precipitation is 56.7 mm, and the annual evaporation rate is 282.3 mm. The average relative humidity ranges between 44% and 70%, with higher readings possible. The average annual wind speed is 8.6–16.2 km/h. The prevailing dry north winds blow on the island all year, cooling it in winter and softening it in summer, while also exposing it to the hot, moist winds of Kos from the south.

3. Material and methods

Due to the scarcity of geomorphological studies on Janan Island, the current study relies heavily on field work as well as satellite images from

Google Earth and the geological map available in Qatar Atlas 2010. Some morphological and topographical equations, such as the form factor, relief ratio, and island isolation index, were used to determine the island's morphological and topographical characteristics. A small motorboat was used to visit the island because it was the only way to get there. During the field visit, measurements and photographs of the landforms scattered there were taken. The small area of the island and its flat surface allowed the researcher to thoroughly study the island. The geomorphological symbols of the landforms were signed, and their locations were determined in the field using a GPS device on a Google Earth image of Janan Island, with the aim of drawing a geomorphological map of the island.

4. Results and Discussion

4.1 Janan Island's natural characteristics

The study of an island's natural characteristics focuses on determining the island's origin, its heights and slope of its surface, and the characteristics of the surrounding waters, as follows:

4.1.1 The island's origins

Qatar is a major convex fold, and a sub-convex fold extends to the west of it known as Jabal Dukhan. The Jabal Dukhan fold in the west is adjacent to a concave fold operated by the waters of Salwa Bay, as well as another concave fold operated by the waters of Zekreet Bay. Janan Island is one of the islands of the northwestern coast, which is the western end of the convex fold of Qatar. The proximity of Janan Island to the northwest Qatari coast is evidence that it was connected to Qatari land before this region was exposed to tectonic movements that led to the formation of the convex and concave folds. The reason for the lack of contact between the island of Janan and the main Qatari land may be due to the emergence of the concave fold that occupies the waters of the Gulf of Zekreet, and it seems that it includes the low areas that are currently submerged by sea water, which separates the island of Janan from the Qatari land (Said, 2023, p. 175).

4.1.2. Elevations

The geological conditions that led to the formation of Janan's island were reflected in its topography in general and in its surface levels in particular, where the difference in the hardness of the rocks played an important role in resisting erosion factors, and thus the values of elevations and slopes varied. Figure No. 2 shows that the general relief difference in its surface is 2 meters, which is the difference between the level of the highest point in the central part of the island, which is 2 meters, and the level of the lowest point (0 meters) in its southeast. It becomes clear that the land of the island has its own topographical

characteristics as it gradually rises from its outskirts towards the center of the island and from the northwest towards the southeast. These elevations generally indicate that the surface of Janan Island is characterized by monotonous flatness and low levels. It is noted from the two figures 4 and 5 the convergence of the contour lines in the southeast, and the main reason for this convergence of the contour lines may be due to the presence of relatively steep low edges.

Figure 4. The contour map of Janan Island

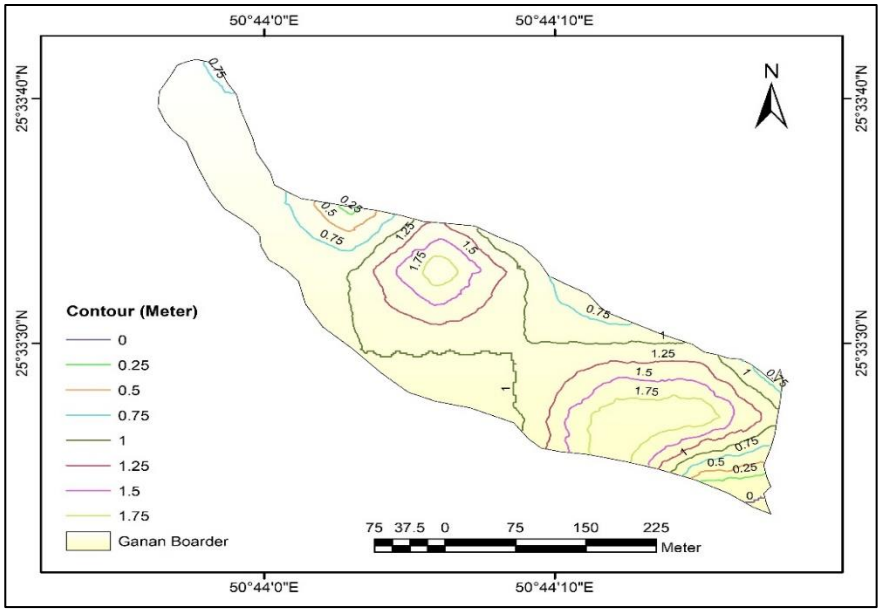
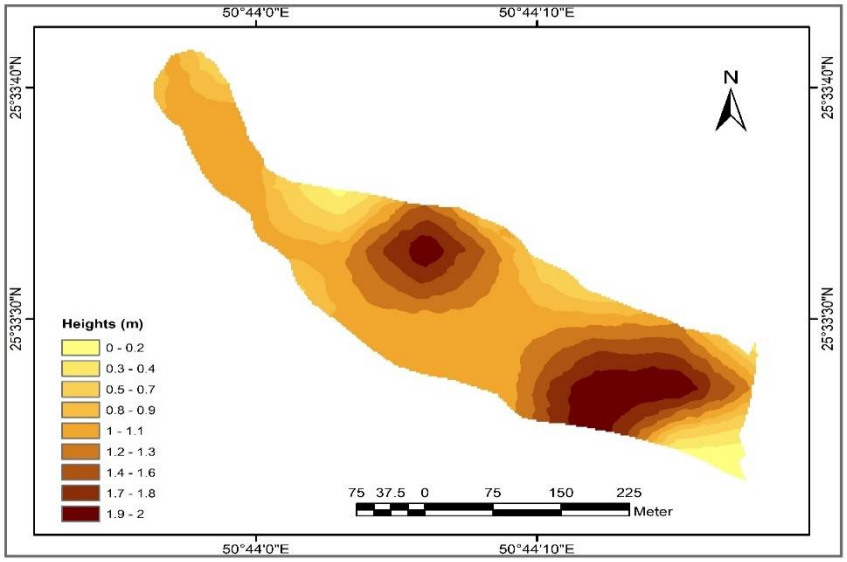


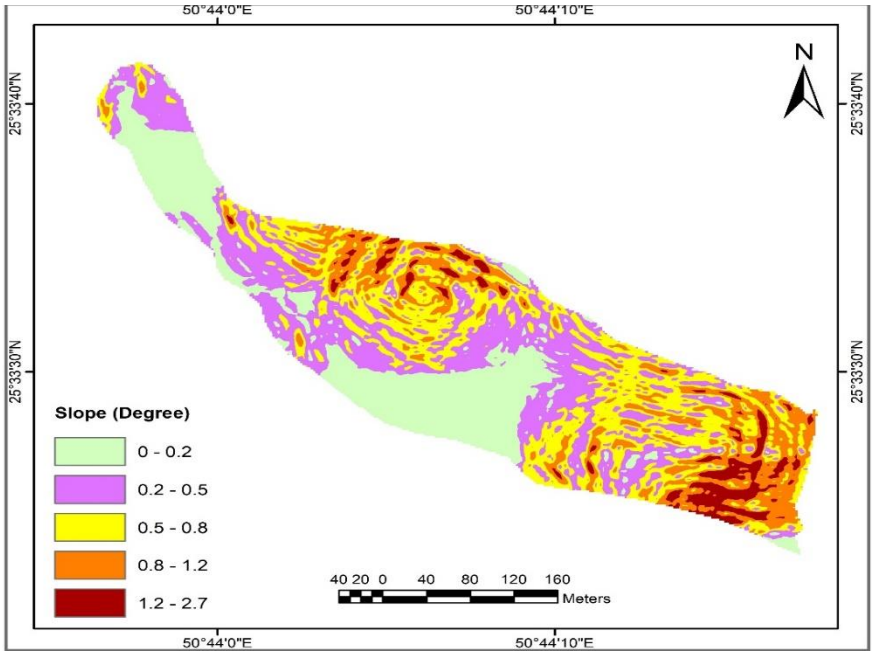
Figure 5. Janan Island digital elevation model



4.1.3. Slope

The slope study aims to identify the nature of the slope of Janan Island's surface and the extent to which the surface is affected by erosion factors, as low slope values indicate the activity of erosion factors and their impact on the island's surface. Figure No. 2 shows that the surface of the island is dominated by gentle slopes, with degrees of slope ranging from 0 to 2.7. A general pattern of decline prevails on the island, with an increase in the degrees of slope from the east and north in the direction of the west and southwest. This pattern corresponds to the general pattern of elevations, and this agreement means that the highest areas of the island are the most ridged and steepest. There is a difference in the degree of slope on different parts of the island. Where there are some parts of the surface in which the slopes suddenly differ from the rest of the surrounding parts, as in the south and north of the island, which appear in green color. (Figure.6), this difference is often attributed to the presence of rocky edges and some small depressions that were formed as a result of the weakness of the hardness of the formations of these areas, which led to an increase in the activity of erosion agents and worked to lower and level its surface. It can be said that the surface of Janan Island, according to Young's classification, falls in the category of flat lands that are characterized by gentle slopes (Young, 1972, p. 173), but there are some steep vertical cliffs that reach 90 degrees in the southeast, and perhaps the reason for this is due to the height and hardness of the formations in these areas, which made them resist erosion factors.

Figure 6. Slopes on the surface of Janan Island

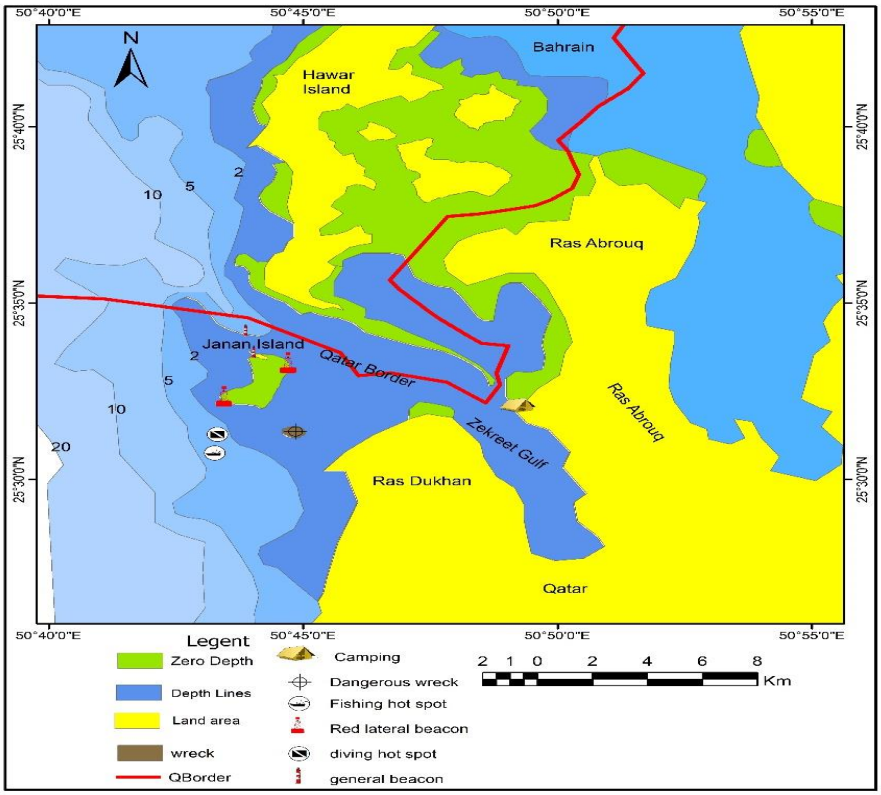


4.1.4. Water characteristics surrounding Janan Island

The water of the Gulf of Salwa, above which the surface of Janan Island emerges, are distinguished by their high salinity of 32 parts per thousand (Ziab, 2001, p. 720). The high salinity of the water is caused by the high average annual air temperature, which is approximately 36.7 degrees Celsius, which increases evaporation processes, as the average annual amount of evaporation is approximately 68.8 mm/m3. Evaporation rates from it, as well as the low amount of rain falling on Salwa Bay, are also contributing factors to the increase in salinity, as the annual average amount of precipitation is approximately 57.2 mm. As a result, it is unable to compensate for the amount of water lost due to evaporation.

The water around the island is also shallow, as depth lines diverge from the island and the Qatari coast, and the depth of the water around the island ranges between 0 and 2 meters (Figure. 7). The Arabian Peninsula's desert, as well as sediments carried by sea currents from the Shatt al-Arab region. A 2-meter depth line is about 2 kilometers from the island's west coast, and a 10-meter depth line is about 5 kilometers away. This is due to the activity of sedimentation processes, as the coast in this sector is distinguished by coral reefs and sandy beaches.

Figure 7. Bathymetric map of Janan Island



According to Figure 7, the shallow water known as the zero depth area surrounds the island from the east for 1 km and extends to the south for 2.7 km, where coral reefs occupy the seabed. While the water depth is 0.5 meters in the northeast, north, and west of the island, it extends for 145 meters, 136 meters, and 237 meters, respectively. The depth of the water then rises to 1 meter in the east, north, and west of the island for distances of 350, 450, and 700 meters, respectively. A public beacon is located in the island's center, and a red side light bacon is located 1 km southeast of the island in shallow water to identify the coral reef area above the seabed. In addition to some other beacons with the goal of guiding and alerting coral reef areas, especially since there is a rocky obstacle that is a dangerous wreck permanently submerged under water in an area ranging between 0 and 2 meters in depth, about 4 kilometers to the southeast of the island.

The shallowness of the water surrounding the island causes the formation of numerous reefs and cays on the island's south and north coasts. The shallowness of the water can be used to enjoy the hobbies of diving and fishing, as there is a hot spot for diving about 4.3 kilometers to the southwest of the island and another hot spot for fishing about 4.6 kilometers away, with water depths ranging from 2 to 5 meters. Locals also camp in the winter over the Zero Depth area on the western coast of Ras Abrouq, about 8.7 kilometers east of Janan Island.

The water surrounding Janan Island are clear because of the lack of water rills in general, as well as the fact that most of the small seasonal water rills pour their water and sediments into shallow depressions spread across the island's surface, preventing their sediments from reaching the sea. Surface water temperatures around the island range from 33.9 degrees Celsius in the summer to 20.7 degrees Celsius in the winter. The high water temperature, salinity, clarity, and shallowness contribute to the growth of coral reefs around the island, which attracts many tourists who enjoy diving to see coral reefs at very shallow depths. There are two hot spots for diving and fishing about 4.3 km and 4.6 km southwest of the island in a marine area with water depths ranging from 2 to 5 meters. The coastal area, located about 8.7 km on the western coast of Ras Abrouq to the east of Janan Island, attracts many local residents who set up their camps in the Zero Depth area (the tidal flat) to relax and enjoy the tranquility and picturesque landscapes.

The coasts of Janan Island are influenced by various water movements represented by sea waves, tides, and sea currents, which have the greatest influence on shaping the island's various geomorphological forms. The average wave height along the island's coast is 0.7 meters. It reaches 1.1 meters in the winter due to the prevailing north and northwest winds. The average wave speed is 21 meters per second. Because of the shallowness of the water off the island's coast, the waves are perpendicular to the coastline, as is typical of shallow sandy coasts (Al-Sheeb, 2004, p. 18). These characteristics influenced the formation

of many marine landforms and sedimentation phenomena on the island's coast, such as sea cliffs, sea stacks, caves, shore platforms, sand spits, and others.

Waves are supported in their geomorphological action by both tidal movement and sea currents. The tides are semi-diurnal and range between 0.01m and 0.69m. This movement causes submergence and receding of water in low-level areas of the island's coast, assisting in the formation of tidal flats (Zero Depth Area) near the island's shores. The movement of the sea currents corresponds to the movement of the prevailing northwest wind. Because it runs parallel to the direction of Janan Island from northwest to southeast at an average Current speed of 0.3–0.4 m/s, its effect on erosion is minor in comparison to its effect on sedimentation. Its main activity is the transportation of sediments from the north of the island and depositing them in the southeast of the island.

4.2. Morphology of Janan Island

Janan Island has some morphological characteristics that demonstrate its significance in terms of its extension in the water of the Gulf of Salwa and its impact on marine erosion processes, which led to it having morphometric characteristics such as length, width, area, and perimeter, as well as applying some morphometric parameters to it and analyzing it as follows:

4.2.1. Spatial characteristics of Janan Island

The study of Janan Island's spatial characteristics focuses on the island's length, width, and perimeter, as well as its area, which has a significant impact on its morphological characteristics. Where the island's area has the greatest influence on the emergence of geomorphological forms and the geomorphological processes that affect them.

Table 1: The spatial characteristics of Janan Island in 2023

Island	Area (km^2)	Maximum length of the island (km)	Square of the length of the island (km)	Average width of the island (km)	Maximum width of the island (km)	Island perimeter (km)	Meandering coastline Length (km)	Straight coastline length (km)
Janan	0.16	0.8	0.64	0.2	0.2	2	2	1.75

Source: Measurements from a Google Earth image and a topographic map of Qatar at 1:250,000

Table (1) shows that Janan Island is unique in a number of spatial characteristics, which we can summarize as follows: Its area is approximately 0.16 km2, accounting for 0.0014% of Qatar's total area of 11636.8 km2. Despite its small size, it was historically very important.

Because it was once a resting place for fishermen, and its future development is anticipated. The island's maximum length from northwest to southeast is about 0.8 km, with an average width of 0.2 km. It has a maximum width of 0.2 km in the center of the island and a minimum width of 0.03 km at its northern end. Its coastline is two kilometers long, and it makes up 4.4% of the total length of the nearby diagonal coastal strip, which is 45 kilometers long. This sector includes the western coasts of Ras Abrouq and Ras Dukhan, as well as the coasts of Zekreet Bay. There is also an increase in the ratio of the length of the coasts of the island to its area, which is 12.5 km / km2. Perhaps the relative increase in the length of the coasts of the island in relation to its areas results from a general increase in the meandering of its coasts, as the rate of meandering reached 1.14.

4.2.2. Morphological characteristics of Janan Island

Some morphometric equations were applied to the spatial characteristics of the island to determine the nature of the shape of the island, such as the form factor, the ratio of length to width, shoreline development index, sinuosity ratio, and isolation index. Given the importance of these transactions in understanding the mechanism of island formation, its geomorphological development, and the geomorphological forms that are widespread in it, as illustrated in Table (2).

Table 2: Morphological characteristics of Janan Island in 2023

Island	Sinuosity ratio	Form Factor	Length/ width Ratio	Shoreline development index	Isolation index
Janan	1.14	0.25	4	2.8	2.5

4.2.2.1. Form Factor

It illustrates the consistency of the general shape of the various parts of the island. It is calculated by dividing the island's area in km2 by the square of the island's length (Horton, 1932, p. 351). The equation's output ranges from 0 to 1. The closer the result is to 1, the more consistent and regular the general shape of the island is; the closer the result is to 0, the less regular the shape of the island is, and it tends to be asymmetric.

When the equation is applied to Janan island, the value of the form factor is 0.25 (Table 1), which is a very low value that indicates the small area of the island in comparison to its length, as well as the elongation of the island and the asymmetry of its general shape. This could be due to lithological differences in the formations that make up the island, as well as being influenced by land movements.

4.2.2.2. Length/ width Ratio

This ratio expresses the island shape's proximity to elongation. This coefficient is calculated by dividing the island's length (km) by its width (km). The geomorphological significance of high length-to-width ratio values indicates an increase in the convergence of the island's shape from the rectangular shape (Gouda Hassanein Gouda, 1991, p. 322).

The length-to- width ratio is 4, which is considered a high ratio, indicating that the shape of the island tends to be rectangular, particularly as its area expands, showing that the island of Janan went through many stages of erosion cycles. The island of Janan's elongation has increased due to the dominance of erosion processes as well as being affected by the joints and cracks that characterize the limestone rocks that make up the island. The high percentage also confirms Janan Island's simple topography and flatness of surface because of the lack of resistance of the limestone rocks that dominate the island to various erosion processes, despite the island's drought.

4.2.2.3. Shoreline development index

The index of shoreline development on the island This ratio can be calculated by dividing the island's perimeter (km) by the square root of the product of multiplying the constant number 3.14 by the island's area (km2). If the result is 1, the shape of the island is circular and more regular; if the result is greater than 1, the shape of the island is less regular and tends to elongate (Seekell, Cael, & Bystrom, 2022, pp. 1-2).

When the equation is applied to the Janan island, it is clear that the indicator of the development of the island's shoreline is approximately 2.8, which is a high ratio, indicating the elongation of the island's shape and the dominance of the processes of erosion and erosion of its shoreline, which lead to the retreat and regression of its Coasts.Sinuosity
4.2.2.4. Sinuosity ratio

It is the ratio between the real length of the shoreline with its meanders to the straight line that connects from its beginning to its end. The ratio expresses the general shape of the straight shoreline in relation to the lithological characteristics that influence its development (John , 1991, p. 46).

The Sinuosity ratio of Janan Island's coasts rises to 1.12, indicating frequent overlapping of land and water. The lack of a significant increase in the meandering coefficient value can be explained by the straightening of some of its coasts due to the presence of sea cliffs, which reflects the general homogeneity of its rock formation, which is composed of limestone.

4.2.2.5. Island isolation index

This indicator calculates the square root of the shortest distance between the island and the mainland of the State of Qatar to determine how isolated the island is from the mainland. Low values indicate that

the island is close to the mainland and easily accessible to residential areas there, and vice versa (Ratter, 2018, p. 11).

The shortest sea distance between Janan Island and the mainland of Ras Dukhan, which is located to the southeast of the island, is about 6 kilometers. After applying the isolation index equation, we find that its value is low and amounts to 2.5 (Table 1). It indicates a slight isolation of the island from the residential areas on the mainland. It is a very low value when compared to the isolation index of some other islands around the world, such as the German island of Amrum, which recorded an isolation index of 11, Aruba, Venezuela, which recorded an isolation index of 18, and the Cook Islands in the South Pacific, which recorded an isolation index of 106 (Ratter, 2018, p. 11). The low value of the isolation index is due to the proximity of the island to Qatari land. The researcher noticed that despite the low value of the island's isolation index, the population rarely visits it, and it lacks development processes, which indicates that there are other factors that contribute to the isolation of the island, which is not determined only by the distance between the island and the mainland. Janan Island's isolation can be attributed to its geopolitical location, which caused political problems between Qatar and Bahrain over ownership of the island, particularly during the process of demarcating the two countries' maritime borders, where a conflict took place in international arbitration for ten years over the eligibility of either of the two countries to have sovereignty over the island, and the conflict ended. With the International Court of Justice ruling on Qatar's right to sovereignty over Janan island.

4.2.3. The island's topography

The study of the island's topography demonstrates the significance of the activity and strength of erosion processes, the impact of lithological and tectonic differences on this activity, the factors that contributed to the island's emergence, and the island's geomorphological stage (Gouda Hassanein Gouda, 1991, pp. 322-323). The island's topography can be identified by the following:

4.2.3.1. Relief Ratio

The relief ratio is one of the most important morphometric parameters that express the relief of the island in relation to its length, and it is calculated by dividing the difference between the highest and lowest points in the island along its length (Schumm, 1956, p. 612).

Table 3: Topographical characteristics of Jinan Island in 2023

Island	Highest point on the island (meters)	Lowest point on the island (meters)	Relief Ratio	Hypsometric Integral
Janan	2	0	2.5	0.1

It is clear from Table (3) that the value of the relief ratio is 2.5 meters per km, which is a low value due to the increase in the length of the island at the expense of its heights. The low value indicates that the island of Janan's surface is less rough, that it is advanced in its geomorphological stage, and that its surface is flat. The low percentage of relief may be due to the island being penetrated by forked water rills, which are distinguished by the shallowness of their streams and the lack of clarity on their sides. The nature of the formations and their lithological characteristics that make up the island had an impact on the lack of relief, as its surface consists of quaternary formations, the majority of which are formed in erodible limestone formations. and carving and reduction caused by abrasion and erosion.

4.2.3.2. Hypsometric Integral

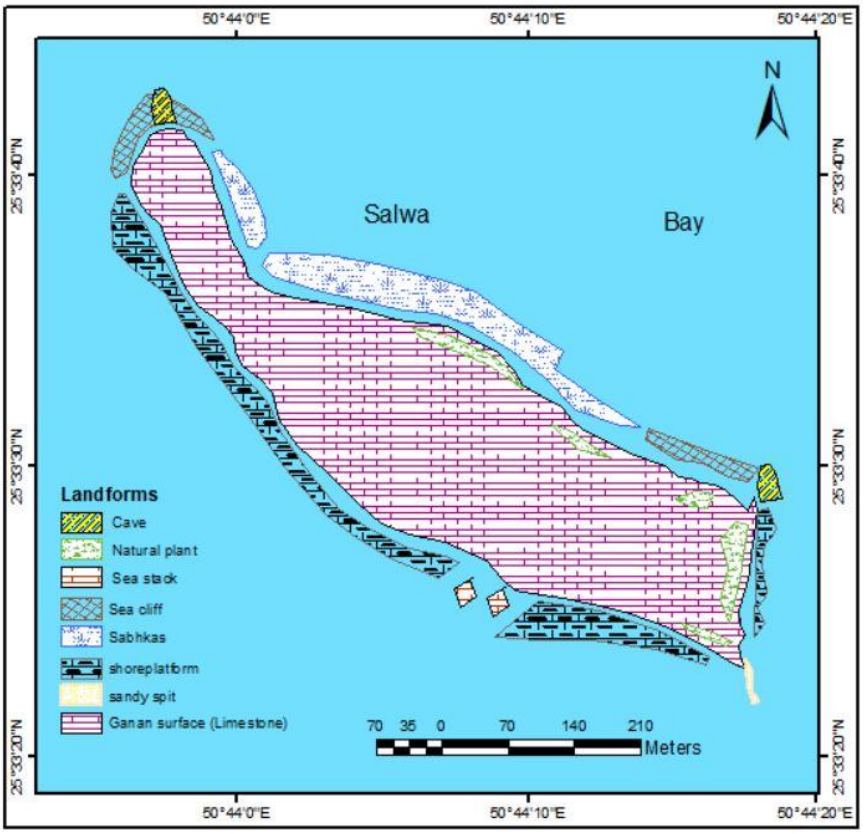
There are many geomorphological phenomena on the island of Janan that indicate that it is going through an advanced geomorphological stage in its erosion cycle due to its wide plain range, which is crossed by small forked waterrills, in addition to its absence of high relief forms, all of which are manifestations indicating the progress of the island in its geomorphological stage. Hypsometric integration is considered one of the most accurate coefficients that represents the time period cut off from its erosion cycle (Torab, 1984, p. 182). The value of hypsometric integral can be extracted by dividing the area of the island (km2) by the topography of the island (meters) (Mustafa, 1982, p. 217).

The hypsometric integral of Janan's island is 0.1 (Table 4). This means that erosion factors have removed 90% of the island's surface, leaving only 10%, indicating that the island has cut off a long period of its erosive cycle and is now in the geomorphological old stage. The island's progress in its geomorphological stage could be attributed to the carving and lowering of its surface caused by the cutoff of its surface by the small valleys spread across it. The sediments resulting from erosion and reduction are deposited as alluvial fans in the broadened plain range. The sea also played a role in lowering parts of the surface of its eastern sides and building its relatively wide coastal plain in previous periods when it had higher levels than it does now, through marine erosion processes during its flood over it.

4.3. Geomorphological Landforms

The field study of Janan Island demonstrates the emergence of natural interactions between land and water along the island's coastline. Because of the movement of sea water represented by waves, tides, and sea currents, as well as the movement of sediments along the shoreline (Yuxin & Xiyong , 2020, p. 4). many phenomena of erosion and marine sedimentation are spread along the island's coasts (Figure 8), such as:

Figure 8. Geomorphological map of Janan Island



4.3.1. Coastal cliff

Active cliffs are spread on the northern and eastern coasts of the island, consisting mostly of limestone rocks with many cracks and joints and suitable for carving operations, as these cliffs are still exposed to sea carving and undermining. The different movements of seawater and the chemical weathering processes in the exposed rock areas during low tide periods helped to form these cliffs. Its height does not exceed 2 meters (Figure 9).

Figure 9

Figure 9. The sea cliff on the eastern coast of the island, showing the impact of various chemical weathering processes, undermining, and the collapsed rock masses, as well as the retraction of the cliff towards the land, leaving a shore platform.

4.3.2. Marine Caves

Some cavities form at the base of the cliffs on Janan Island's eastern coast, and their floors are close to sea level, indicating that they were formed by wave carving and the hydraulic pressure of the waves. The presence of cracks and joints in the rocks, as well as weathering processes, help the waves expand and increase the depth of these cavities in a direction perpendicular to the coastline. At the bottom, weathered sediments and collapsed boulders of varying sizes from the caves' roofs accumulate. The caves range in height from 0.5 to 1 meter, in width from 1 to 2 meters, and in depth from 30 cm to 150 cm (Figure 10).

Figure 10

Figure 10: Marine caves on Janan Island's eastern coast Collapsing rock blocks appear from the cave roofs, as does the accumulation of weathered sediments on the cave floor.

4.3.3. Shore Platforms

The most common geomorphological landforms on Janan Island's coasts are shore platforms. Because of the activity of carving waves and marine carving operations on the island's coast. The shore platforms are formed as a result of cliffs receding towards the island's coastline. The shore

platforms have a gentle slope of 2° to 6° but end in a more sloping frontage to the sea.

The shore platforms consist of soluble limestone rocks. As the rate of carving in its rocks increases as a result of the increase in the activity of wave carving to a degree that exceeds the strength of its resistance to wave carving (Stephenson, 2000, p. 22). This is consistent with the claim (Carlos López-Fernández, 2020) that the elevation variation on the shore platforms is due to lithological differences. The height of the shore platforms on the coast of Janan Island ranges between 40 and 60 cm above sea level. Therefore, these platforms are considered low-level due to wave activity and other marine operations.

The platforms extend from the high tide mark at the base of the coastal cliffs to a level just below the coastal water level when low tide occurs. The width of the platforms increases with the recession of the cliffs. Its width varies between 15 meters on the eastern coast of the island and 50 meters on the northern coast of the island (Figure. 11). The shore platforms are distinguished by their dynamic equilibrium, and they retreat entirely to the island's coastline. They also tend to stabilize by widening to the point where the waves can no longer carve the base of the coastal cliff, and this happens because the low tide does not induce a retraction of the cliff (Moursi, 2020, p. 153).

The shore platforms' surfaces have some small pits and solution pools, which are more common on horizontal rather than inclined surfaces. They develop on land as a result of the flow of sea water as well as the action of grinding sand, gravel, and rocks. These pits have developed from pits and small holes whose diameters do not exceed a few millimeters. These pits are filled with water continuously, even during low tide periods, due to their lower level than the level of the shore platform dug above. Some fragments and rock masses resulting from the retreat of the cliffs are also scattered. In addition to the large number of cracks and joints that take directions perpendicular to the sea and directions parallel to it, weathering is active along these cracks, which ultimately leads to the activity of dissolving them and lowering their surface levels (Figure. 12). The shore platform also permeates the tidal water, thus forming a tidal channel characterized by narrowness, depth, steep sides, and many meanders (Moursi s. M., 2022, p. 1533).

Figure 11. One of the shore platforms on the east coast of Janan Island, showing the motorboat that was used to reach the island

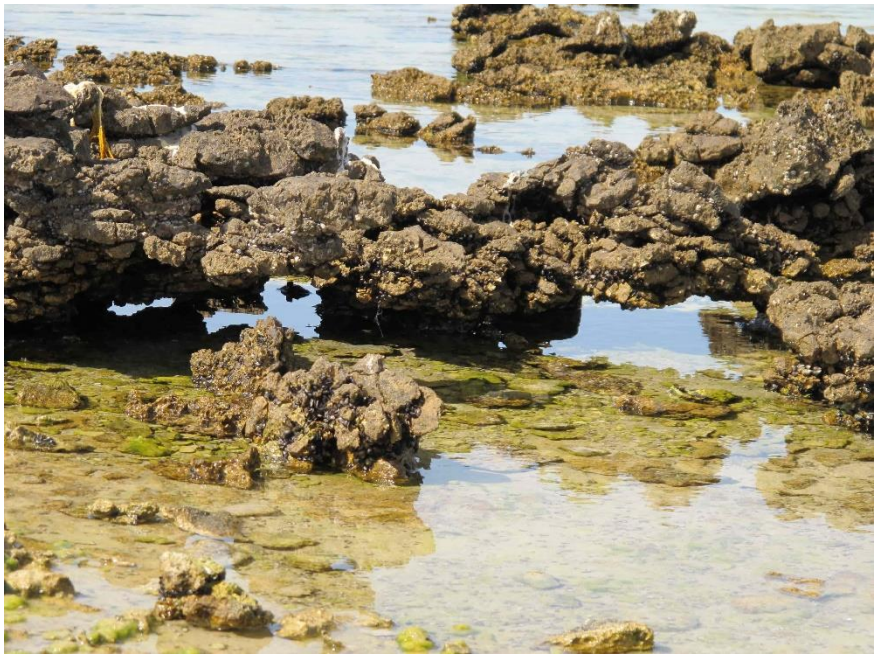
Figure 12

Figure 12. Shows the vertical lowering of a shore platform. On the northern coast of Janan Island, where different levels appear in the shore platform.

4.3.4. Marine Arches

This phenomenon was recorded on one of the small headlands extending from the western coast of the island towards the sea (Figure. 13). The arches are formed as a result of the carving of waves on both sides of the headland due to the difference in the direction of the waves. As the water permeates intensively on both sides of the headland, it eventually forms a waterway in the headland through which seawater is delivered. The arches are low in height and short in width. The reason for this may be due to the low level of the surface of Janan Island. The height of the arches ranges from 50 cm to 75 cm and often does not exceed 1 meter in height, while their width increases compared to their height, as their breadth ranges between 1.5 meters and 2 meters. The arches are narrow and low in height. The reason for this may be the low level of the surface of Janan Island. The height of the arches varies from 50 cm to 75 cm and rarely exceeds a meter, while their width increases compared to their height, ranging from 1.5 meters to 2 meters.

Figure 13. The marine arches off Janan Island's western coast. Its height is low in comparison to its width. It is also noted that the water is shallow and contains green algae and coral reefs.



4.3.5. Headlands and Bays

Due to lithological factors, some rocky heads protrude from the coast of Janan Island towards the sea water, particularly on the island's southwestern coast. Where the heads arise as a result of the different degrees of hardness of the limestone rocks that make up the island's coast line, and because the ancient marine sculpting factors, particularly

the waves, were more active and powerful than they are now; therefore, the waves chose to carve in areas of rock weakness in those rocks, such as cracks and joints, and in places of less solid rocks, leaving the most solid and highly resistant rocks to carve prominent and extended into the sea in the form of headlands protruding from the coastline of the island into the sea (Figure. 14).

The headlands contain some semi-circular bays, which are considered a suitable environment for sedimentation operations. The shape of the bays, their breadth, the degree of penetration into the island's coast, and the degree of curvature of their coasts are determined by the various factors that contributed to their formation. The headlands and the bays surrounding them increase the meandering of the island's coastline. The more the erosion in the sides of the headlands increases, the more the headlands penetrate into the sea, and thus the neighboring bays penetrate more into the island's coastline. The length of the headlands in the sea ranges between 10 and 13 meters, while the depth of the bays along the coastline of the island ranges between 11 and 20 meters. The water is characterized by its shallowness in the bays and around the headlands.

Figure 14. One of the headlands and one of the bays on the southwestern coast of Janan Island, along with three sea stacks, appear in a straight line. It is also evident that there is a small headland exposed to waves attack. It is clear that the middle section of it represented a marine arch, and then its roof collapsed and became two sea stacks.

4.3.6. Sea Stacks

Sea stacks can be defined as one of the landforms consisting of a steep and often vertical mass of rock located in the sea near the coastline of the island and formed by the carving of waves. Sea stacks separate from the steep side of the headlands. Sea stacks are the remaining portions of the surface of the shore platform left over from receding cliffs.

The rock properties are important in the development of the rocks on the headlands, from which the sea stacks separate. The greater the number of cracks and joints and the higher the porosity, the greater the likelihood of rock collapse and disintegration, as well as the formation of sea stacks. Since the rocks that make up the headlands that extend from the coast of the island towards the sea are composed of limestone rocks highly susceptible to weathering and landslides, the majority of the headlands is subject to weathering processes as well as the fall of boulders and rock fragments from the upper parts of the headlands. The effect of sudden rainwater, which may run as minute rills on the surface of the heads and permeate the cracks, accelerates their fall. The lack of vegetation in the headlands also increases the activity of landslides and, as a result, their slope.

Some sea stacks are scattered on the southwestern coast of Janan Island, ranging in height from 1 to 1.5 meters. Traces of various weathering processes appear on the stacks, as well as traces of undercutting and oxidation processes in their lower parts. These stacks approach the coastline of the island; they are found on the same extension line, which suggests that they represent the old coastline of the island while the new coastline recedes behind it (Figure 14).

4.3.7. Sand Spit

Sand covers the surface of the marginal band that surrounds the outskirts of Janan Island, particularly in the southeastern end, where these sands accumulate because of the effects of the prevailing northwest winds. At the southeastern end of the island, the sands extended into the seawater by a joint action of the prevailing winds, waves, and sea currents and formed a sandy spit.

A sandy spit is formed by the breaking and deflecting waves. The waves slow down near Janan Island because of the shallow water surrounding it. When the waves approach the northwestern coast of the island, they deviate to the other back coast that is protected from wave attack, which is the southeast coast of the island. Where the waves transport and collect sediment from both sides, and the process of collecting and accumulating sediment continues until it emerges above sea level in the form of a sandy tongue that extends from behind the island towards the mainland next to it.

A sandy spit runs northwest to southeast along Janan Island's southeastern tip, varying in length from 34 to 48 meters (Figure.15). The

tides cause the difference in the length of the spit, with water covering about 14 meters from the spit's tip that extends into the sea during high tide. While the length of the spit increases due to the receding of seawater at low tide due to the lower level of the spit's surface. It has an average width of about 7 meters, a width of about 12 meters when it connects to the island, and a width of about 3.5 meters when it ends in the sea. The height of the spit's surface does not exceed 50 cm above the water surface when it connects to the surface of the island. The spit's two sides are distinguished by their gentle slope, with the northeastern side's slope not exceeding 2 degrees and the southwestern side's slope exceeding 3 degrees. This is due to increased deposition rates on both sides of the spit. The spit deposits consist of white calcareous crumbles, mostly coarse to medium sandy deposits, and a few fine ones.

Figure 15. A sandy spit at the southeastern end of Janan Island, and it is noticeable that coral reefs (Al-Fashot) are spread in front of and on both sides of the spit.

4.3.8. Coastal Sabkhas

Sabkhas are areas of flat, low-lying land with wet salt deposits along the shorelines of Janan Island (Figure. 16). The level of the Sabkhas scattered along the island's northern coast ranges from sea level at its outer edges, close to sea water, to 2 meters at its inner edges, close to the island's coastline. During high tidal periods, the Sabkhas are exposed to seawater inundation as sediment is deposited on their surfaces, while the water is confined to them during low tidal periods, when the water returns to the sea, carrying with it quantities of sediment that return it to the sea. As a result of the dominance of the water of the high tide in the winter, the Sabkhas appear wet and saturated with water and appear in the form of temporary swamps, which quickly dry up in the summer and appear as salt flats (Al-Turkmani, 2000, p. 194).

The Sabkhas range in width from 20 to 50 meters, and the flatness of the northern coast of the island, as well as its low levels, contributed to the dominance of seawater over it. As a result, the width of the sabkhas is determined by the topography of the site, so that they are narrow where there are sea cliffs, as on the island's eastern coast, and wide where these cliffs retreat towards the island's coastline away from the sea, as on the island's northern coast (Ashour, 1989, p. 24).

The materials that make up sabkhas sediments include salts from seawater evaporation, clay and calcareous sediments washed away by rainwater, and sandy sediments thrown over the surface of the sabkhas by prevailing northwest winds. The presence of Sabkhas helps protect the coast of the island from erosion because they reduce wave action and trap many sediments. It also works to reduce the intensity of surface runoff because it slows down the movement of rainwater and absorbs a large amount of it. Sabkhas also maintain the quality of rainwater by filtering impurities from the water and assisting in metabolic processes. The Sabkhas are also economically significant because they provide good habitat for fisheries. It protects and feeds many different types of marine fish (Noaa, 2023).

Figure 16. Coastal Sabkhas on the northern coast of Janan Island, an increase in water content is noted at its edges close to the sea, while its inner edges far from the sea appear dry, and some green algae are spread over its surface.

4.3.9. Dray water Rills

The water rills originate from the relatively high areas in the center of Janan Island during the rainy periods of the Pleistocene era and are

short, narrow, and shallow. The vertical difference between the bottom of the rills and the tops of its sides is not more than 50 centimeters, while its width does not exceed 50 meters, in addition to its gentle slope as it slopes towards the sea or descends towards the low areas above the surface of the island. The island acquired its previous characteristics as a result of the reflection of its surface features and the scarcity of its rain.

Water rills are distinguished by their dryness, with water flowing only intermittently depending on rainfall and quantity. When it rains, it does not fill the entire stream but rather one of its sectors. As a result, the surface running water appears to have no effect on the formation of the grooves and features of the island's surface but rather is limited to leveling the surface and obliterating its features. This is demonstrated by the water rills' interactions with various geographical factors, such as: 1. A scarcity or lack of rain: Where rain is characterized by its scarcity or lack in general. The annual rate of precipitation on the island ranges between 44 and 90 mm, and it all falls in short periods. 2. Surface flatness: The island's surface is flat, with low elevations and simple slopes, affecting the amount of running water. Where the water spreads over the surface of the island at a level that aids in water leakage or evaporation, resulting in an increase in surface water loss, and thus the amount of water remaining on the surface of the island is sparse and incapable of carving the rocks and forming the rugged areas on the surface. As a result, the water rills appear as indistinct surface lines covered by natural vegetation and sand. 3. Island surface rocks: The permeability of the rock and its ability to seep water vertically into the ground influence the drainage of Janan Island's water rills. The surface rock formations of the island are made up of limestone rocks that are notable for their permeability and porosity. Where there are many cracks and joints that increase their permeability to rainwater, the rainwater dissolves the calcareous formations mixed with evaporator sediments, which seep with the water in the rock towards the ground, blurring the features of the surface water rills over the island's surface (Figure 17).

Figure 17. Show one of the shallow water rills above the surface of the island. Natural vegetation occupies the bottom of the rill, which leads to blurring of the rill's features.

5. Conclusion

The objective of the current study was to study the geomorphology of Janan Island, which is one of the small islands scattered on the northwest coast of the State of Qatar. The importance of Janan Island is due to its geopolitical location, which is very close to the maritime boundary line separating the State of Qatar and the Kingdom of Bahrain. The field study revealed many geomorphological forms on the island. The digital elevation model of the island was used to detect the water-rills on the surface of the island, in addition to their heights and slopes. Many morphological and topographical treatments have been applied to determine the shape of the island and the geomorphological stage it is going through. The results of the study indicate that the island consists of limestone rocks of varying degrees of hardness and resistance to erosion factors. The concave Zekreet fold caused the separation of Janan Island from the Qatari coast. The current study shed light on the spatial characteristics of the island, which were reflected in its morphological characteristics. Where the island is distinguished by its small area and its different dimensions, which made the shape of the island closer to the elongation and rectangular shape, which indicates the activity of carving operations on the coasts of the island, and the increase in the tortuosity of its coasts as a result of the large number of overlaps between land and water.

The study also highlighted the topography and geomorphological characteristics of the island. It turned out that it is distinguished by its

flat, low surface and its gentle slopes with low relief, and the value of the hypsometric integration indicates that the island is undergoing a geomorphological old stage. The geomorphological map also sheds light on the types and locations of landforms scattered along the island's coasts, such as active sea cliffs, caves, shore platforms, sea stacks, sandy spits, Sabkhas, and dry water rills, in addition to the various erosion factors that contributed to their formation, such as waves and sea currents. And the tides and prevailing winds in the study area, which helps in knowing the locations of the landforms in order to be able to enjoy their landscapes or study them in detail. In addition, the bathymetric map of the island highlighted the importance of the possibility of developing the island and taking advantage of its shallow water and coral reefs to practice camping, fishing, and diving.

The current study indicated a decrease in the value of the island's isolation index due to the closeness of the island to the mainland, despite the island's proximity to the Qatari coast and the enjoyment of many natural ingredients that qualify it to become a tourist island in the first place, but it is not inhabited and is not visited by tourists or the local population. Therefore, the current study proposes linking Janan Island with the mainland at Ras Dukhan by constructing a bridge with a length of about 6 km or by filling in part of the shallow water area separating Janan Island and Ras Dukhan with a length of 6 km and a width of 1 kilometer, so that it can benefit from the bridge and the establishment of some resorts and tourist facilities. Adequate publicity for the island and highlighting its natural features and the beauty of its beaches and coral reefs to encourage local and foreign visitors to visit the island. Allocating motorized boats as public transportation for all visitors to address the lack of means of access to the island The current study is considered the first building block for various future geomorphological studies on the island of Janan, such as studying the change of the land cover of the island through satellite images in different time periods, studying the effect of sea level changes on the island, and studying the coral reefs around the island.

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