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THE INFLUENCE OF CLIMATIC AND GEOMORPHOLOGICAL PROCESSES ON LANDFORM DEVELOPMENT IN SAWA LAKE / IRAQ

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Abstract: Sawa Lake is a unique, ecologically important, closed-basin lake located in the Muthanna governorate of southern Iraq, in the arid zone of the Mesopotamian region. It is characterized by the absence of apparent inlets or outlets and maintains a relatively stable water level through underground artesian spirals and outflow. Sawa Lake has a distinctive milieu with high saline and alkaline levels, unlike any other in the region, which supports specialized microbial life. The study focused on the significant and unique natural topography characteristics of Sawa Lake, located in Muthanna Governorate, approximately 25 km from the center of Samawah District, with an area of 5.5 km². The lake is distinguished by the density and salinity of its water, which surpasses that of seawater. The study indicated that the lake is distinguished by a variety of landforms created through geomorphic processes, including mechanical and chemical weathering, influenced by groundwater that has impacted the predominant limestone and gypsum rocks in its geological formations. These rocks are susceptible to decomposition and dissolution, resulting in a variety of geomorphological features both within and surrounding the lake. The lake is encircled by saline limestone cliffs interspersed with other topographic elements that slope towards the lake's center, such as cracks or springs that supply water to the lake. The lake's water level fluctuates between wet and dry seasons due to climatic variations that occur annually, influenced by the prevailing arid conditions of the region. Additionally, the lake is currently experiencing desiccation due to the diminishing water levels of subterranean reservoirs, such as the Dammam and Euphrates Reservoirs, which supply the lake from significant depths, and this is exacerbated by the proliferation of groundwater wells in the desert.

Keywords: geomorphic processes, Iraq, mechanical weathering, Muthanna Governorate, Sawa Lake

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INTRODUCTION

Sawa Lake is a natural, enclosed lake that receives no inflow from any surface stream. It was created by geological and structural processes resulting from the Euphrates Fault or the Abu Al-Jir Fault, which impacted the area and stretched from Hit in the north to northwest Basra in the south. The process led to the creation of interconnected water springs, resulting in a rift measuring 20 meters in width and 40 meters in length, which provided the lake with water from subterranean sources (Radeef & Abdulameer, 2023). The Sawa lake basin is typically elongated, with its length nearly four times its breadth, suggesting a near-rectangular shape due to the disparity between vertical and lateral erosion (Al-Musawi & Al-Sulaiman, 2023; Ministry of Environment, 2018).

The morphological shape is like to a pear, and its salinity level exceeded 3600 parts per million, a notably high concentration, being 1.5 times saltier than the Arabian Gulf and possessing greater salinity than the Dead Sea, which has a salinity of 260 parts per thousand. The waters are saturated with sulfate, magnesium, and sodium salts, exhibiting a high density that surpasses that of seawater, with ocean water density ranging from 1.021 to 1.027, the Baltic Sea at 1.01, and the Red Sea at 1.028, while Lake Sawa's density reached 1.1 (Al-Quraishi, 2013).

The lake features varied landforms created by natural influences, including tectonic movements, climate variables affecting geomorphic processes, and the characteristics of its waters. These influences influenced its rocks, resulting in unique formations that distinguish it from other lakes globally. The adjacent salt cliff, a significant geomorphic landform, results from the ongoing deposition of salts along the shore, which accumulates in thickness over time.

The occurrence of salt caves distributed nearly along the lake's perimeter is a notable geomorphological feature of the lake, akin to the presence of salt cocci resembling cauliflower florets (Al-Quraishi, 2013), alongside the proliferation of salt marshes and gypsum along its shores, as well as the presence of water springs and limestone caves within its central region (Awadh & Muslim, 2023) (Figure 1).

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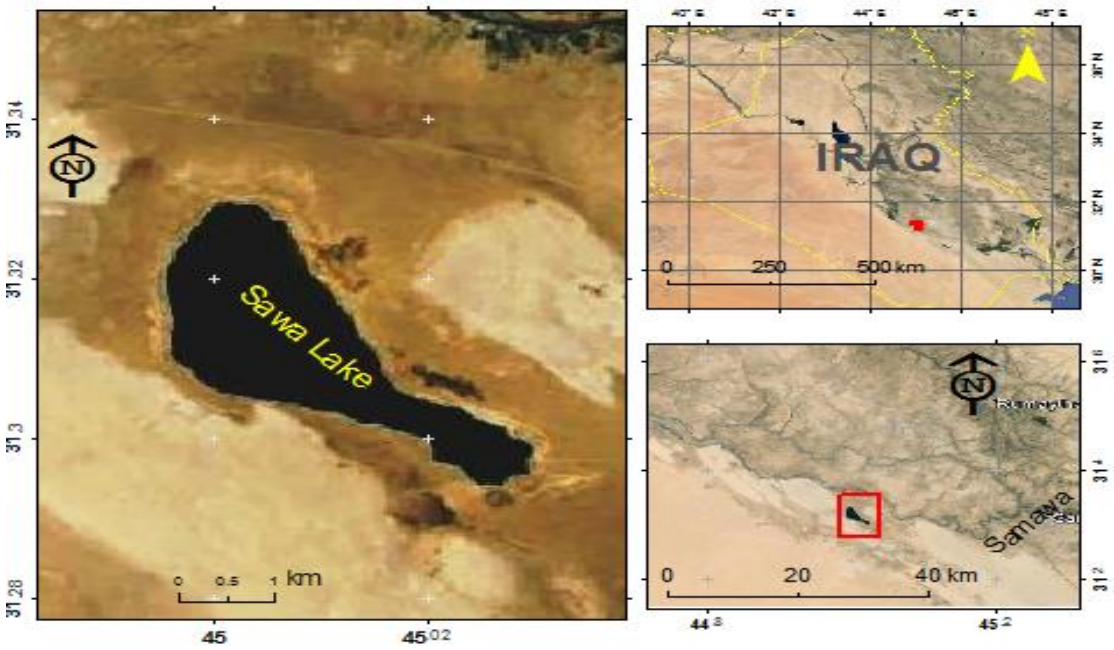

Figure 1. Shows Saw Lake ecosystem (Source: Abed, 2017)

Research inquiry: What processes and geomorphological elements contributed to the formation and temporal evolution of the surrounding landforms at Sawa Lake?

The study hypothesizes: that Sawa Lake contains a variety of unique landforms shaped by a combination of climatic conditions and geomorphic processes that contributed to their development.

The research objectives are to examine the influence of climatic factors and related geomorphological processes on the formation of landforms surrounding Sawa Lake, as well as to investigate the factors driving geomorphic development in the area by analyzing the origins, emergence, and natural influences contributing to these landforms.

MATERIALS AND TECHNIQUES EMPLOYED

The study was conducted following multiple field trips to the lake to assess its topography and observe the variations and fluctuations in its levels and their effects on the evolution and alteration of its landforms. Field measurements were done during the study, and coordinates were established at the visited sites using a GPS device. Prior scientific literature examining the lake was utilised, employing geospatial tools (GIS) to augment the research data.

1. Location of Sawa Lake

Sawa Lake is situated at a longitude of N31°.298′.52" east and a latitude of E45°.029′.79" north, in the southwestern region of Iraq, within the administrative confines of Muthanna Governorate. Map (1) indicates that the lake lies approximately 25 km southwest of the Samawah District center, with an area of roughly 5.5 km², with a length of around 5 km and a circle of 12 km. The lake basin is elongated, with its length nearly four times its breadth, suggesting a near-rectangular shape, attributable to the disparity between vertical and lateral erosion (Ministry of Environment, 2018).

2. Topography of Lakes

The lake is situated on very level terrain, with an elevation between two contour lines (15.5-17.75) above sea level. The lake's most significant topographical characteristic is its elevation above the surrounding terrain by over five meters, resembling a bowl elevated above the ground. Consequently, it is only visible from a short distance near its perimeter. The sides or edges incline towards the center of the lake.

3. Geology of Lake

The study area is situated in a tectonic region of the Arab-Nubian surface, specifically at the transitional zone between the stable platform of the Salman range and the unstable platform of the sedimentary plain, particularly within the Euphrates belt, noted for its substantial thickness of recent sediments from the Euphrates River. Faults and folds constitute the fundamental structural makeup of the studied region. The stable platform in this region was influenced by a series of northwest-southeast trending faults originating from the Triassic period. These predominantly elongated faults are the most recent and significantly impact the surface. Notably, the Euphrates fault and the Abu Al-Jir fault, which runs parallel to the western side of the Euphrates River, are critical in the formation of Lake (Al-Asadi et al., 2024). The stratigraphic column of the lake reveals that the predominant formations, arranged from oldest to youngest, are:

- Dammam Formation (Lower Eocene - Upper Eocene)

The Dammam Formation is prominently visible across extensive regions from the central and western areas of Al-Muthanna Governorate to the southern vicinity of the lake. Most water wells penetrate this formation, which comprises

layers of clay interspersed with Neolithic limestone, subsequently followed by recrystallised limestone and additional limestone, culminating in the Siwan knot (Majid et al., 2025). The formation's thickness ranges from 100 to 200 meters. The Dammam Formation comprises limestone rocks, which are particularly susceptible to dissolution, contributing to the lake's morphological peculiarities (Abed et al., 2022; Jamil, 1977).

- Euphrates Formation (Late Lower Miocene to Middle Miocene)

The Euphrates Formation is partially exposed (Al-Jiburi & Al-Basrawi, 2007) to the east of the lake and comprises Cretaceous limestone in unconformity with the Dammam Formation, featuring alternating limestone and mudstone, along with limestone interspersed with marl. The upper contact is congruent with the Nafael layer.

The Euphrates Formation is visible in the southern section of the research region, namely 1 km south of Lake. This formation comprises grey to yellowish-gray rock masses, with a thickness ranging from 30 to 40 meters (Al-Naseri et al., 2023). This formation primarily consists of limestone, which includes some coral reefs.

- Nafael Formation (Middle Miocene)

This formation is located in a particular area in the southeastern region of the governorate. The geological formation has been designated as the Nafael Formation (Hussein, 2024; Rafa'a & Buthaina, 2009; Sissakian, 1999; Sissakian & Buthaina, 2007; 2018 ,حميد العبدان). The formation comprises two sections: the bottom section features a sequence of green shale interspersed with limestone, while the higher section contains a series of red and brown silt and clay rocks, with thin limestone layers at its base.

- Contemporary sediments (Pleistocene-Holocene)

Pleistocene sediments denote river terraces, whereas Holocene sediments encompass valley sediments, desiccated lakes, depression sediments, slope sediments, and sabkha (Al-Mubarak & Amin, 1983; Khaldoun, 2009).

4. Climatic characteristics

Climate is a crucial component influencing natural studies, particularly geomorphological research, due to its effect on the geomorphological processes that shape landforms.

The historical climate existing in the Muthanna desert

The ancient climate of each geological age influenced landform development through the sediments deposited throughout the geological crises of those periods. During the Tertiary era, the climate of the Western Desert region and the study area was akin to the present climate, characterized by a predominantly arid environment with intermittent humid phases. This conclusion is predicated on a series of climatic indicators, exemplified by evaporative rocks in the Injana and Al-Fatha formations, alongside the occurrence of clay minerals, specifically palygorskite, which emerge in arid climatic conditions within the Umm Ardma, Akashat, Al-Fatha, Injana, Al-Zahra, and Al-Manshara formations in the Muthanna desert (Al-Attiyah, 2002; Al-Fanharawi & Al-Khafaji, 2023; Genchev & Gartsiyanova, 2024; Majid et al., 2025)

The prevailing climate of the Muthanna desert and the research

The study area's climate is categorized as arid, situated within Iraq's dry climate zone, where summer temperatures exceed 40°C for four months (June, July, August, September), as indicated in (Table 1). The annual average temperature is 25.4°C, while winter temperatures drop to 6.5°C in January. The significant temperature disparity resulted in an augmented thermal range between summer and winter, with the annual thermal range attaining 14.5 m.

Table 1. Shows the annual average temperature (˚C), humidity %, wind speed m/second, and rain fall (mm) (Climate data of Al-Samawah Station for the Period 1993-2022)

Months	**Average Temperature (˚C)**	**Maximum Temp (˚C)**	Min Temp(˚C)	Humidity %	Wind speed m/second	Rain Fall (mm)
Jan	**11.7**	**17.7**	**6.5**	**63.1**	**2.9**	**22.1**
Feb	**14.4**	**20.9**	**8.4**	**54.5**	**3.3**	**14.8**
Mar	**19.4**	**26.1**	**12.6**	**43.2**	**3.6**	**18.4**
Apr	**25.4**	**32.2**	**18.3**	**36.2**	**3.7**	**11.2**
May	**32.0**	**39.1**	**24.2**	**26.3**	**3.8**	**4.3**
Jun	**35.8**	**43.5**	**27.0**	**21.7**	**4.3**	**0.0**
Jul	**37.4**	**45.1**	**28.6**	**21.4**	**4.1**	**0.0**
Aug	**37.2**	**45.4**	**28.1**	**23.1**	**3.7**	**0.0**
Sep	**33.3**	**41.8**	**24.5**	**26.4**	**3.3**	**0.2**
Oct	**27.3**	**35.4**	**19.9**	**35.3**	**2.9**	**5.2**
Nov	**18.4**	**25.8**	**12.8**	**53.0**	**2.6**	**20.9**
Dec	**13.6**	**19.6**	**8.2**	**62**	**2.7**	**14.5**
average	**25.4**	**32.7**	**18.2**	**38.8**	**3.40**	**9.3**

This phenomenon influences geomorphological processes, including physical and chemical weathering, which impact rocks through thermal expansion and contraction, hydration, desiccation, and decomposition, thereby contributing to the formation of varied landforms surrounding the lake. Rainfall is minimal and varies annually, averaging 57 mm in 2008 and approximately 247.9 mm in 2013. Nevertheless, the annual total precipitation is typically low, measuring (111.6) mm from (1988-2022), accompanied by elevated evaporation rates, particularly during the summer months due to high temperatures and a four-month absence of rainfall, with peak evaporation occurring in July

and August at (558.1, 523.8) mm, respectively. It diminishes significantly during winter, attaining 85.9 mm in January. The elevated evaporation rates during the summer season resulted in significant evaporation of the lake, leading to an increase in the salinity of the water, with total dissolved solids (TDS) reaching 31,898 parts per million and electrical conductivity (EC) measuring 47,620. In contrast, in January, TDS was 30,431 and EC was 43,473.

Furthermore, evaporation contributed to a decline in water levels, exacerbating drought conditions due to prolonged periods of insufficient rainfall, which is primarily confined to the winter season (Al-Sakni et al., 2024). This situation adversely affects the lake's replenishment areas, specifically the groundwater reservoirs in the southern Badia, and directly impacts water levels through surface evaporation, further intensifying drought conditions.

Wind and humidity

a. Wind speed escalates in June and July, attaining values of 4.3 m/s and 4.1 m/s, respectively, then declines to its minimum of 2.7 m/s in November.

b. Humidity exhibits elevated levels throughout winter, peaking in January at 63.1%, and diminishes in summer, attaining its nadir in July at 21.4% due to the intensity of heating.

5. Geomorphic processes and the resultant landforms in Sawa Lake

Geomorphic processes, including physical and chemical weathering, facilitated by groundwater, influence the dissolution and alteration of gypsum rocks within the geological formation (Webb et al., 2024), resulting in various geomorphological features that exhibit unique phenomena and aesthetically pleasing shapes near the lake, as detailed below:

a. The coast

The area is delineated by the boundaries established by high tide, which are shaped by low tide. According to Davis's classification of coastlines, they are categorised into submerged and elevated coasts. Consequently, the coastlines of the study area can be classified into two principal types: the first comprises low or submerged sedimentary coasts (Mahsoub, 1986; Nabil & Israa, 2025), while the second consists of cliff or elevated coasts. The first type encompasses the majority of the northern, eastern, and southeastern shores of the lake, where sedimentary characteristics are evident. The second kind is characterized by the western beaches of the study region, where coastal platforms vanish and drop directly into the water, forming active cliffs that exhibit erosion features (Al-Abbadi, 2013; Mousa et al., 2022).

b. The rocky cliff

The rocky cliff signifies the rugged terrain that directly overlooks the body of water. The construction of rocky cliffs (Figure 2) initiates with undermining from beneath, resulting in an erosional gap where the cliff's base seems to hover above the water surface. The ongoing erosion and weathering caused by waves at the base of this edge results in its retreat and the creation of a rocky platform where the land has receded (Tareeh, 1993).

The lake is encircled by rugged cliffs on all sides. They comprise hard rocks interspersed with soft rocks. The resilient rocks exhibit significant resistance to erosion and manifest as elevated, sharp cliffs. The elevation of the rocky cliff varies from the lake by approximately 3 to 5 meters.

Figure 2. Shows the rocky cliff surrounding the Sawa Lake/ Samawah / Al Muthanna province /Iraq (Source: Authors)

Figure 3. Shows the basal gaps between rock in Sawa lake/ Samawah / Iraq (Source: Authors)

- Basal cavities

There are openings distributed at the base of the steep cliff encircling the lake. They are created through water erosion and the sculpting actions exerted on the cliff by the incessant movement of waves, along with the dissolution and erosion affecting the weaker underlying rocks, leading to the development of transverse cavities and apertures. These features were created during the epoch of water abundance in the lake when the water level ascended to the rocky precipice (Figure 3).

- Weathering and its subsequent forms

Weathering is the process of disintegration and decomposition of rocks, soil, and minerals at or near the Earth's surface due to prevailing atmospheric forces, without the displacement of fragments from their original location.

- Mechanical weathering

This is the process by which rocks are dissolved, broken, and shattered into smaller sizes and forms without any alteration in their chemical composition. This is the initial phase that readies rock post-disintegration for erosion, transportation, or chemical weathering processes. Physical weathering predominates in the study area, recognized as one of the most dynamic forms of weathering due to its arid conditions. The climate significantly influences this process through temperature fluctuations and extremes, the characteristics of precipitation, and wind intensity. Furthermore, the sparse vegetation cover exacerbates these factors, leading to the disintegration of surface rocks into particles that contribute to the formation of diverse land features (Al-Asadi et al., 2024; Al-Fanharawi & Al-Taee, 2022). The types of mechanical weathering impacting Lake include:

Evaporative salt weathering

Salt weathering occurs in Lake, where salt crystals induce rock disintegration and layer peeling by exerting pressure in confined rock spaces and pores as they expand. This process enhances weathering, amplifying the effects of thermal expansion in various minerals and rocks, such as granite and limestone. The coefficient of longitudinal expansion of rock salt at a temperature of 40 °C is calculated to be approximately 40.4 × 10^-6/°C. Gypsum and sodium chloride are among the most significant salt minerals that contribute to this process (Ramadan, 2004). This process is regarded as the predominant mechanism in the creation of landforms in Lake. Owing to its elevated salt concentration. Due to elevated temperatures, particularly during the summer months.

Weathering through consecutive cycles of soaking and drying

Mechanical weathering transpires due to the repetitive cycles of wetting and drying in the soil, which create fissures resulting from volumetric expansion (swelling) during the wetting phase after winter precipitation. This is followed by contraction during summer droughts (Awadh et al., 2022), exacerbated by elevated temperatures and evaporation, ultimately leading to the fracturing, swelling, and peeling of rocks and soil (Figure 4).

Figure 4. Shows the distension and exfoliation of rocks resulting from repeated cycles of wetting and drying /Sawa Lake / Iraq (Source: Authors)

The - Landforms produced by chemical weathering

The processes of hydration and carbonation

This is a chemical weathering process, including the combination of water or its vapors with certain elements of rock minerals, leading to the production of honeycomb-like structures (Figure 5) due to the influence of rainwater or lake waves that infiltrate the rocks. The study area possesses sufficient water for this process, resulting in the widespread occurrence of this weathering type in limestone rocks, which exhibit increased solubility in water containing dilute carbonic acid. This acid is generated during the carbonation process through the reaction of water with carbon dioxide, either from the atmosphere or soil, as illustrated in the following equation:

CO2 + H2O ↔ H2CO3 ↔ H+ + HCO3-

Carbonic acid interacts with the limestone diluent, yielding hydrogen ions as represented in the equation:

CaCO3 + H2CO3 → Ca (HCO3)2

This is characterized by the remarkable capacity to disintegrate the minerals of these rocks, dissolve them, and disassemble their components (Mahsoub, 1986).

Figure 5. Shows the phenomenon of hydration and formation of honeycomb-like structures /Sawa Lake / Iraq (Source: Authors)

Figure 6. Shows the salt caves and dissolution caves Sawa lake / Iraq (Source: Authors) /Sawa Lake / Iraq (Source: Authors)

Salt caves

Caves commonly form along the fault lines of cliffs subjected to wave action. They are salt caverns characterized by a white hue at their entrances and ceilings. They comprise solidified salt crystals with a conical shape that tapers downward, referred to as descending columns. This phenomenon occurs owing to chemical erosion resulting from the breakdown and erosion of a portion of the salt cliff by waves (Al-Dulaimi, 2008), as illustrated in (Figure 6).

Figure 7. Shows the salt Domes (cauliflower flower) distribution in the area surround Sawa lake / Iraq (Source: Authors)

Salt Domes

Among the picturesque geological formations along the coast of Lake are the phenomena of cones or rock domes, as well as the so-called salt caves. These caverns resemble a pear blossom. Observe in Figure 7 their dispersion near the coastline originating from the rocky cliff region, where they diminish and fade towards the lake, remaining closely

clustered before progressively separating and fading as proximity to the lake increases. Their creation results from the ongoing accumulation of salts on the shallow waterbed, subsequently reaching the water's surface level. As deposition persists, the water level ascends, and following the crystallization of salts, particularly in the higher region, evaporation occurs, leading to hardening that resembles the aesthetic of a cauliflower flower (Al-Dulaimi, 2008).

Karst dissolution landforms

These landforms result from the influence of water on rock formations, since the study area experiences dissolution processes due to the presence of soluble rocks that dominate the creation of the basalt and the dam, which serve as groundwater reservoirs in the region (Kurniawati et al., 2020). The stratigraphy of these two reservoirs comprises layers of limestone, dolomite, and anhydrite, indicative of limestone formations featuring numerous conduits, caves, and caverns.

They comprise weak binding elements that are water-soluble, along with the impact of these layers on structural deformations, manifested as faults, joints, and fissures that contribute to the rock's weakening through dissolving. The foremost of these forms are:

1. Water springs

Due to the presence of the Abu Qir fault, the lake is dotted with springs that emerge from limestone distributed in the Dammam and Euphrates formations or reservoirs, where some springs were formed and over time the water from these springs eroded the rocks (Figure 8), thus connecting with each other, A crack about 40 meters in length and 20 meters in width may have developed at the center of the lake, resulting from this fault. Analysis indicated that the lake water contained salt chloride (Mohammed & Qais, 2014).

2. Limestone caves

The creation of limestone caves in Sawa Lake results from geological formations of materials susceptible to dissolution and chemical weathering, specifically limestone and dolomite. This event contributed to the formation of the lake by the dissolving of rock facilitated by groundwater saturated with carbon dioxide. The cave walls exhibit calcium salt deposits formed by the evaporation of lime-saturated water, imparting a whitish hue. They exhibit a broad, transverse, and low morphology, suggesting their formation occurred at the interfaces of rock layers with distinct sedimentation processes (Karbal, 2011).

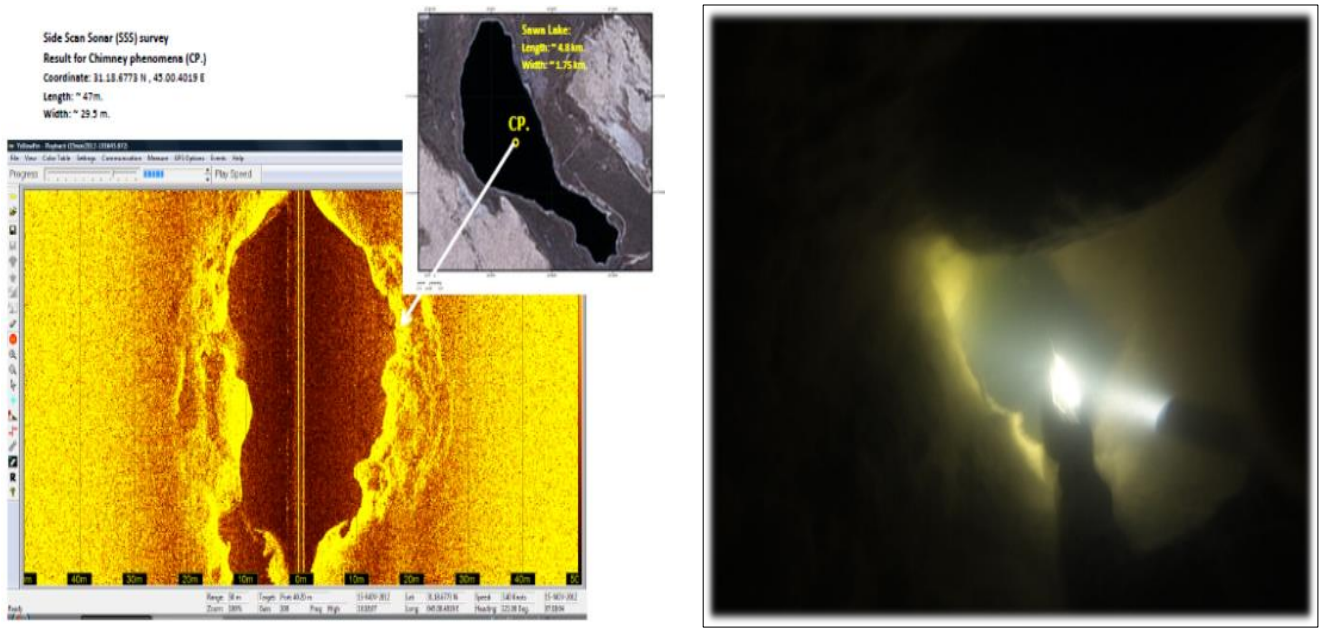

Figure 8. Saw Lake / Iraq; A: Shows an aerial photo of one cracks feed the lake and caves within its depths that were formed by the dissolution process and structural factors of the cracks; B: Shows the water springs feeding the lake (Ministry of Environment, 2018)

3. Erosion of limestone

This phenomenon is common on the study area's rocky cliff slopes. Raindrops penetrate the rock fissures because of their extreme ruggedness and lack of vegetation cover, which causes them to gradually expand, giving the geomorphic appearance distinct, jagged surfaces. A number of elements contributed to their creation, including the high permeability of limestone and the profusion of joints and fissures (Mahsoub, 1986).

Landforms produced by metadynamic processes

Debris flow is a morphological dynamic process that is influenced by gravity, topography, climate, water movement between weak rock parts in the study area's geological structure, or the concentration of upper rock layers on soft, slippery rocks. These factors eventually cause the rocks to separate and split, and they slide or fall on the lake's bottom cliffs, forming various forms such as rock rolling, rock sliding, and rock falling, as illustrated in Figure 9.

Figure 9. Shows the Sawa lake / Iraq. A: The rockslide phenomenon that occurred in from rock separating and splitting; B: Multiple splitting of rocks in Sawa lake (Source: Authors; Location: Sawa Lake / Iraq, April , 2024)

Landforms of wind origin:

1- Sand dunes

The sand dunes are one of the most important Aeolian features of Sawa Lake and are located in its western part. Several factors play a fundamental role in the formation of sand dunes, including the availability of sand sources in geological formations, strong winds capable of carrying grains, vegetative barriers, and rocky cliffs that hinder the movement of wind and force it to deposit its load, forming these northwest-southeast oriented ribbons of sand dunes (Figure 10).

Figure 10. Shows Al-Nabaq dunes adjacent to Sawa Lake / Al Muthanna Province/ Iraq (Source: Authors)

Figure 11. Shows the quagmire that goes parallel to Sawa's Lake shoreline/ Iraq (Source: Authors)

Evaporative landforms

1. The Quagmire

It is a level region with salts all over it, which are produced by variations in the groundwater level. The dissolved salts rise together with the groundwater level when it rises. A solid salt layer known as the quagmire covers the surface when temperatures rise because a significant portion of the water evaporates (Al-Khaiqani & Al-Husseni, 2025) quagmire go parallel to Sawa's Lake shoreline (Figure 11).

2. Gypsulfate

In the study location, where a belt forms around the lake on all sides, this phenomena is well known. Gypsum is a reflection of the alternating rainy and dry seasons; rain breaks down gypsum from the region's layers, and capillary action causes groundwater to rise, which dissolves a large portion of the gypsum that has previously been formed.

It might have developed as a secondary layer brought about by the hydration of anhydrite minerals during chemical weathering, or it might have been created by the action of sulfate-rich lake waves during evaporation, Figure 12.

It may also be a secondary layer formed by the hydration of anhydrite minerals during chemical weathering, with a thickness of 0.3 to 100 cm (Al-Abbadi, 2013).

Figure 12. Shows the Gypsulfate phenomena surrounded Sawa Lake / Iraq (Source: Authors)

CONCLUSIONS

1. There is no river flowing into Sawa Lake; it is a natural lake. It was created by the Euphrates Fault's structural elements (also known as the Abu al-Jir Fault). Because of the groundwater that comes from the fault's fracture in the center of the lake, it gets its nourishment from deep within the lake. Furthermore, rainwater is its only source of surface nutrients.
2. Natural climatic factors and topographic processes affect the formation of the Sava Lake topography, which in turn affects its rocks and soluble strata, forming diverse topographic forms.
3. The lake is currently drying up completely due to dry climate and haphazard drilling of wells, which has reduced the supply of spring water, thus depleting the underground reservoirs that feed the lake, especially the salt works or so-called salt marshes.
4. Several limitations encountered during this study including the following points:

A. Limited temporal data and a lack of long-term historical data that restricts the assessment of long-term geomorphic evolution of Sawa lake.

B. Restricted the accessibility for certain regions of the lake due to water salinity and terrain constraints.

C. Uncertainty of groundwater dynamic lead to reduce the understanding of the lake's hydrodynamic balance and its reaction with fault structures.

D. Shortage of the high-resolution remote sensing analysis.

E. Excluded of the ecological and biological dimensions because the study focused only on the geomorphic process that could not provide a details environmental perspective such as the microbial life and its interaction with water salinity.

Recommendations

1. The large-scale random drilling of groundwater in the Muthanna Desert and its use for agricultural purposes must be stopped in coordination with relevant departments. Because it threatens the underground reservoirs that feed the lake.
2. Rejuvenate the lake by preventing the salt mines (salt production plants, the main cause of the lake's drying up) from consuming the lake's water.
3. We propose the Lake Sawa /Biosphere Reserve, which preserves the biotope elements of flora, fauna and geological structures within the framework of a natural ecosystem, taking care to protect the unique environment and genetic diversity, without affecting traditional uses.

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