Geomatics Applications in the Study of Geo-Environmental Changes in Alzaytun Basin Wetlands, the Middle of Siwa Depression

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الملخص:

تتمثل الأراضي الرطبة بحوض الزيتون والذي يقع وسط منخفض سيوة في كل من البحيرات والبرك والمستنقعات والسبخات. والتي تتسم بتغيرها المستمر بما فيها من ظاهرات وتعرضها للعديد من الأخطار، والتي تم رصدها عن طريق تطبيق تقنيات الجيوماتكس.

وتعد المياه الجوفية من المصادر الرئيسية التي تقوم بتغذية الأراضي الرطبة بكميات كبيرة من المياه وخاصة العيون المائية. وتتكون منطقة حوض الزيتون من رواسب ذات نفاذية ومسامية عالية والتي أدت إلى سهولة تسرب المياه إلى المناطق المنخفضة مكونة البحيرات والبرك والمستنقعات، كما ساعدت على صعود المياه الأرضية إلى السطح بالخاصية الشعرية وتراكم الأملاح بنسبة كبيرة نتيجة ارتفاع درجة الحرارة والتبخر، لتكون سببا في انتشار السبخات والعديد من الظاهرات الدقيقة على سطحها. كما تعد التدخلات البشرية من العوامل المؤثرة على النظام البيئي الطبيعي للأراضي الرطبة، كانتشار الأراضي الزراعية، والمراكز العمرانية، والطرق.

وتعد الأراضي الرطبة مظهراً مورفولوجياً مميزاً داخل حوض الزيتون لما تقوم به من وظائف إيكولوجية وبيولوجية لحفظ التوازن البيئي داخل الحوض، كما تقوم بتنقية وترشيح المياه التي تمر بها وبالتالي تعمل على تغذية خزانات المياه الجوفية. وقد بدأ الاهتمام بها في الآونة الأخيرة واستغلالها اقتصاديا في العديد من الأنشطة، وخاصة: استخراج الأملاح، والسياحة البيئية والعلاجية.

Abstract:

Wetlands in Alzaytun Basin, the middle of Siwa Depression, include lakes, swamps, marshes, and sabkhas. Because of their inherent features and their constant exposure to dangers, they are prone to a continuous change that has been monitored by applying geomatics techniques. One of the main sources that provide wetlands with large amounts of water is groundwater, and especially water springs. Alzaytun Basin area consists of sediments with high permeability and porosity that facilitate water infiltration into the low areas forming lakes, swamps and marshes. These sediments also help groundwater rise to the surface by capillary action and the high amounts of salt accumulation as a result of high temperature and evaporation, which cause sabkhas and many subtle features to spread on the surface. Human interventions, such as agricultural, urban, and road expansion, are also among the factors affecting the natural ecosystem of wetlands. Wetlands in Alzaytun Basin, however, are a distinct morphological feature because of their ecological and biological functions that preserve the environmental balance within the Basin: They purify and filter the water passing through, and thus feed the groundwater reservoirs. Attention to wetlands has recently begun, and they have been economically exploited in many activities, especially in salt extraction, and ecological and therapeutic tourism.

Keywords: geomorphology of wetlands, soil sediments, quality of wetlands, salt formations

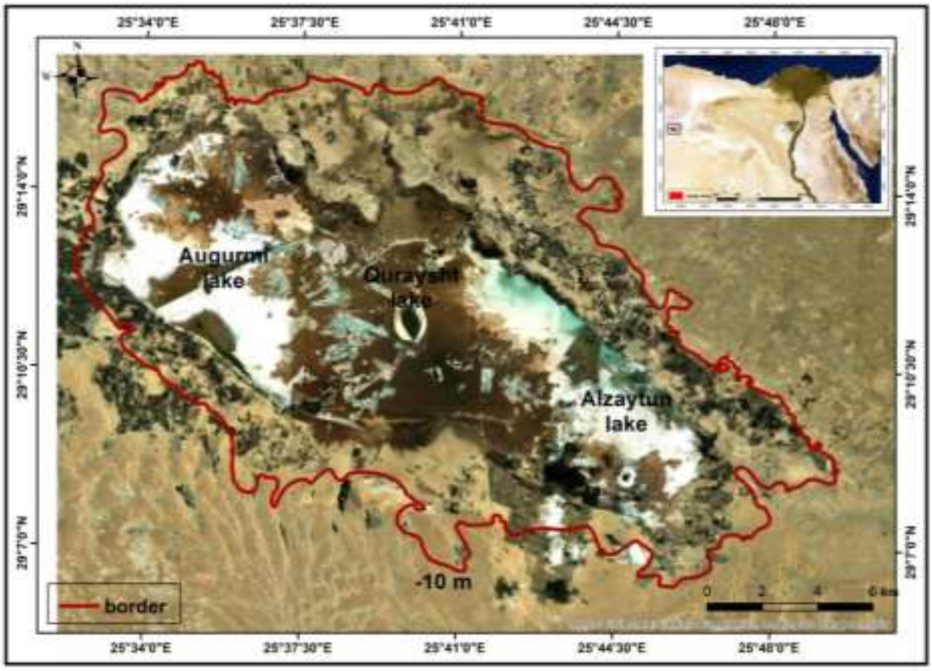
1. Introduction

Geomatics techniques are among the advanced scientific tools, recently used in studying the geomorphology of wetlands and in monitoring the relevant environmental changes in order to accurately get, analyze, and process information before incorporating it into an integrated database. Wetlands are those lands that are saturated with surface and/or ground water for some time enough to support the life of plants, animals, birds, and aquatic organisms. They can also be defined as lands flooded with shallow water ranging from a few centimeters to six meters (Shaltout, 2011). The geomorphological features therein vary between lakes, swamps, and (wet &/or dry) sabkhas, where the latter could include such subtle features as salt blisters, domes, polygons, and korchev.

Significant as they are for their ecological and biological functions in maintaining the environmental balance, in addition to their economic importance as a main source of fish and animal wealth (Saber, 2022), wetlands urgently need to be globally protected, especially because they are deteriorating much faster than other ecosystems do. Procedures of protection have already started with Ramsar

Convention in 1971 that is an international agreement for the conservation and wise use of all wetlands around the world. Yet, further actions, related to modern scientific applications, are required.

Alzaytun Basin is located in the middle of Siwa Depression, the Western Desert, between El-Mo'asser Basin to the east and Siwa Basin to the west; and is approximately 300km far from the Mediterranean coast. The Basin from southeast to northwest is maximally 30km long, while from south to north it is about 18km wide. The Basin bottom is semi-rectangular in shape, and most of the Depression lands are located -10m below sea level. The 301km^2 area extends between latitudes 29°6′12″, 29°16′00″N, and longitudes 25°32′45″, 25°49′30″E. Alzaytun Basin is bordered on all sides by a contour line of -10 meters (see Figure 1).



Source: Esri, Maxar, Earthstar Geographics, and the Gis User Communi

Figure 1: *Alzaytun Basin, Siwa Depression*

Wetlands in the study area include lakes, swamps, marshes, sabkhas, natural springs and wells (see Figure 2). There are three important lakes in the Basin: (a) Augurmi Lake in the west of the Basin at a level of -16m and an area of 5.51km^2, (b) Quraysht Lake in the middle of the Basin at a level of -20m and an area of 0.63 km^2, and (c) Alzaytun Lake in the west of the Basin at a level of -18m and an area of 8.96km^2. These lakes, which are among the lowest parts of the Basin, represent 5.02% of the total area. They are the main food source for the birds migrating from Asia and Europe.

Source: Field Study (2022)

Figure 2: *Diversity of Wetland Forms in Alzaytun Basin, Siwa Depression*

2. Review of the Literature

Researchers, such as Aql (2003), Abdul Hameed (2008), Khader (2008), Saber (2015), and El-Sherbiny (2022), have attempted the subject of the present study. Aql (2003) examined soil desertification in Siwa Depression from a geomorphological perspective through studying the features of the natural environment and soil desertification in the Depression. Using remote sensing data in examining the geographical and geomorphological characteristics of wetlands and in monitoring the relevant morphological changes therein, Abdul Hameed (2008) tackled wetlands in Al-Ahsa area. In an applied geomorphological study, Khader (2008) conducted geographic information system (GIS) techniques to investigate the natural and morphological characteristics of Siwa Depression. Saber (2015) studied the geo-environmental changes in the wetlands, to the east of Manzala Lake, through following the development of wetlands in terms of their general, natural, and chemical characteristics and their biodiversity, using topographic maps, satellite visual applications, and GISs. Finally, El-Sherbiny (2022) analyzed and modelled soil salinity in Siwa Depression, with a special attention to soil salinity factors, soil properties, water resources and their relationships to soil salinity, statistical analyses of soil properties, and evaluation of soil productive capacity.

The present study, however, is intended to widen the perspective of the study insofar as it comprises four interrelated approaches, drawing up a complete and true image of the study area that emphasizes the scholarly richness of the present study itself.

3. Objective of the Study

This study aims to apply geomatics techniques to the study of wetlands in order produce a modern digital map intended to classify wetlands, and to monitor the relevant environmental features, changes, and risks. It also seeks to propose the appropriate solutions for confronting those risks and reducing their potential occurrences. Targeting the goals of sustainable development, it throws light on the natural environmental resources in the study area for the purpose of evaluating them and determining how to economically benefit therefrom.

4. Analysis

Based on its terminal objective, the present study is designed to proceed with the analysis from four interrelated approaches, all of which address the use of geomatics applications in the study of the geological changes observed in Alzaytun Basin wetlands. The first is concerned with the environmental factors affecting the geomorphology of the

Basin, namely, the spatial analysis of both natural and human environmental factors. The second focuses on soil sediments of Alzaytun Basin wetlands. The third detects the geomorphological changes in the area. The fourth investigates the quality of wetlands to answer to the question of their significance. In the final analysis, the study draws up concluding remarks that are developed into results and recommendations for future research.

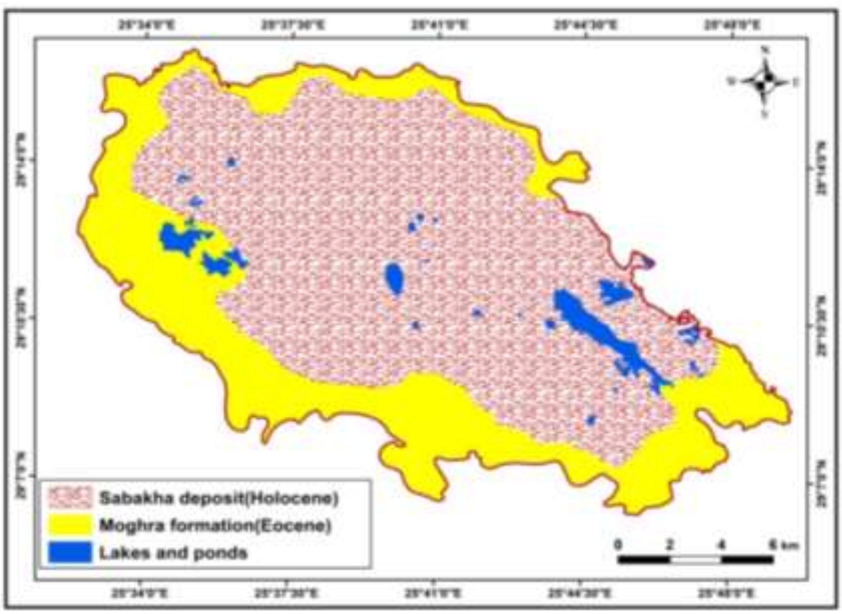
4.1 Environmental Factors Affecting the Geomorphology of Wetlands, Alzaytun Basin

4.1.1 Spatial Analysis of Natural Environmental Factors

There are many natural characteristics that affect the emergence and development of wetlands in the area. They range from those of geological and terrain fields to those of the climate. Each group diverges into minor factors adding to the overall analysis. The climatic characteristics, for example, comprise various elements that play an important role in changing the area of wetlands.

4.1.1.1 Geological Characteristics

Figure 3 and Table 1 show that the geological formations in Alzaytun Basin are dating back to the Eocene era in the third stage and to the Holocene era in the fourth stage. Moghra formation, for instance, belongs to the Eocene era (Said, 1962), and its sediments consist of sandstone, sand, limestone, and shale. It spreads southeast, south, west, northwest, and north of the Basin. It covers an area of 95.28km^2, representing 31.65% of the total area of the Basin. As for the surface sediments, they belong to the Holocene era, and are represented by the sediments of swamps and sabkhas. They spread over the central area of the Basin bottom, consisting of fine sand, loam, mud, shale, and a large amount of salt in an area of 205.72km^2 that represents 68.35% of the total area of the Basin.



Source: Geological Map of Egypt (Conoco), at a scale of 1:500,000, Siwa Oasis in 1986

Figure 3: *Surface Geological Formations and Sediments in Alzaytun Basin Area*

Table 1: *Surface Geological Formations and their Proportions in Alzaytun Basin Area*

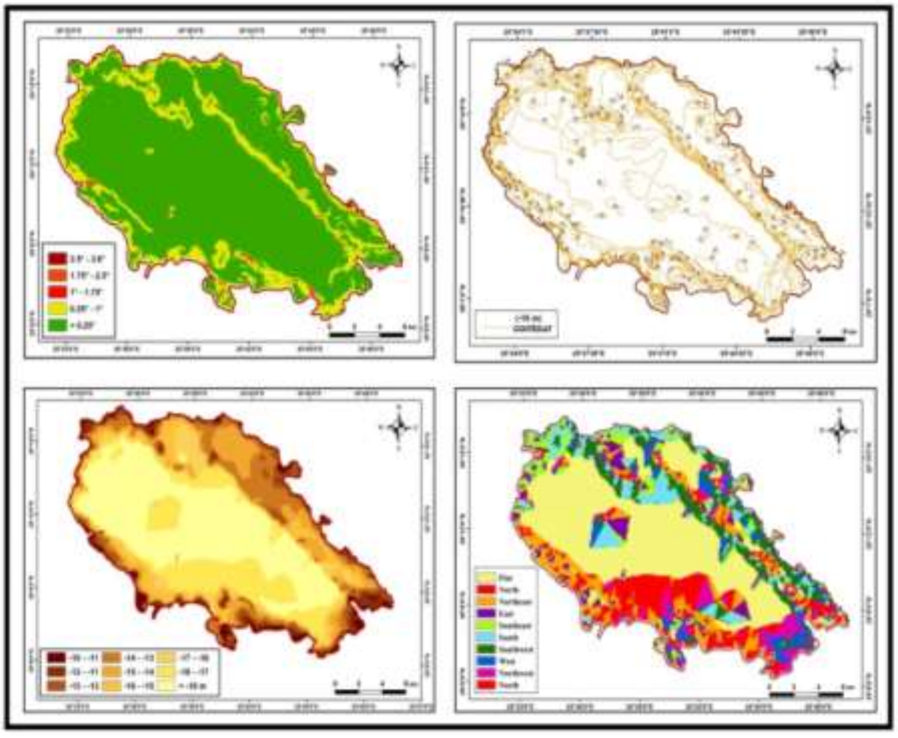
Geological time	Geological Formation	Area	
		km^2	%
The Fourth time(Holocene era)	Lakes and ponds	8.14	2.71
	Sabakha deposits	197.58	65.64
The Third time(Eocene era)	Moghra formation	95.28	31.65
Total area	—	301	100

Source: Adapted from Figure 3. using Arc Map 10.6.1

Based on examining the geological characteristics of Alzaytun Basin, it turns out that geological formations contain high amounts of sediments with high permeability and porosity, which facilitate water infiltration from such neighboring areas as agricultural lands and self-flowing water from springs into the low areas. These sediments also make groundwater rise to the surface by the capillary action, causing salt accumulation as a result of evaporation. They finally result in the spread of swamps, marshes, and sabkhas in many areas of the Basin.

4.1.1.2 Terrain Characteristics

Studying the terrain characteristics helps identify the general features of Alzaytun Basin surface. The levelness of the surface and the slight slope are among the factors that contribute to the spread of wetlands in the Basin. In addition, it makes them as suitable as the other areas that could be variously exploited for human uses. This is evidenced by the study of heights, slopes, and terrain percentages (see Figure 4, & Table 2).



Source: Topographic Maps, at a scale of 1:500000; and DEM of the Study Area

Figure 4: *Terrain Characteristics of Alzaytun Basin*

Table 2: *Terrain Characteristics of Alzaytun Basin*

Height			Degree of Slope				direction of Slope		
Classes	Area		Classes	Slope adjective	Area		Slope direction	Area	
	km^2	%			km^2	%		km^2	%
-10 : -11	12.7	4.21	< 0.25	Very light	240.4	79.86	Flat	112.63	37.41
-11 : -12	13.1	4.35	0.25 – 1	Very light	58.3	19.4	North	52.9	17.58
-12 : -13	16.7	5.54	1-1.75	Very light	1.5	0.48	Northeast	32.14	10.67
-13 : -14	30.6	10.16	1.75-2.5	Very light	0.6	0.19	East	14	4.66
-14 : -15	29.2	9.75	2.5-3.6	Light	0.2	0.07	Southeast	15.26	5.07
-15 : -16	22.6	7.5	-	-	-	-	South	25.76	8.56
-16 : -17	17.8	5.91	-	-	-	-	Southwest	24.03	7.98
-17 : -18	49.7	16.51	-	-	-	-	West	9.3	3.09
> -18	108.6	36.07	-	-	-	-	Northwest	14.98	4.98
The total	301	100	The total	–	301	100	The total	301	100

Source: Adapted from Figure 4, using Arc Map 10.6.1

As indicated in Figure 4 and Table 2, height, degree of the slope, and direction of the slope are so distinct in nature that tracing their characteristics can give a true image of Alzaytun Basin wetlands as a whole. They need to be closely examined as an elaboration of the terrain characteristics of the study area. The following remarks show their significance.

- **Height**

Levels range from -10m to less than -18m below sea level. The geographical scope, ranging from -10m to -11m below sea level, is 12.7km^2, representing 4.21% of the total area. It includes sandy areas and parts of dry sabkhas. On the other hand, the geographical scope, ranging from -11m to -18m below sea level, is about 179.7km^2, representing 59.72%., and including some sabkhas, and water bodies, such as Augurmi Lake, Alzaytun Lake, swamps, and drainage basins. Still, the geographical scope of -18 below sea level is 108.6km^2, representing 36.07% of the Basin total area, extending in the middle of the Basin within areas of salts, wet sabkhas, swamps, and such lakes as Quraysht Lake. Of all the three scopes, the latter proves the largest and deepest.

- **Degree of the Slope**

The slope of Alzaytun Basin surface is highly slight. The area, where the slope is less than 2.5°, is about 300.8km^2, representing 99.93%. Compared to the other parts of the study area, it is thus the largest. It is concentrated in flat lands, especially those in the sabkhas extending around the lakes. As for the areas with a slight slope ranging from 2.5° to 3.6°, they occupy an area of 0.2km^2, representing 0.07% of the total study area. They extend on the western side of the study area.

- **Direction of the Slope**

The analysis here distinguishes between Four Parts of the Basin.First, the area of flat regions is 112.63km^2, representing 37.41% of the total area of Alzaytun Basin. These regions occupy the central part, and some northern and eastern parts of the Basin. Secondly, the regions with a northern slope are 52.9km^2 in area, representing 17.58% of the total. Thirdly, the regions with a northeastern slope are 32.14km^2, representing 10.67%. Fourthly, the regions, whose slope takes a southwest, west, and northwest direction, is 48.31km^2, representing 16.05%.

Based on the above analysis, Alzaytun Basin areas tends to be of a low local relief. The contour lines diverge in slightly sloped regions that occupy large areas of the Basin center. They are low regions, resulting in forming wet and dry sabkhas, swamps, and marshes. The contour lines converge in small regions in the southern, southwestern, western, northern, and eastern parts of Alzaytun Basin. This is all caused by some elevations, such as sand dunes.

4.1.1.3 Climatic Characteristics

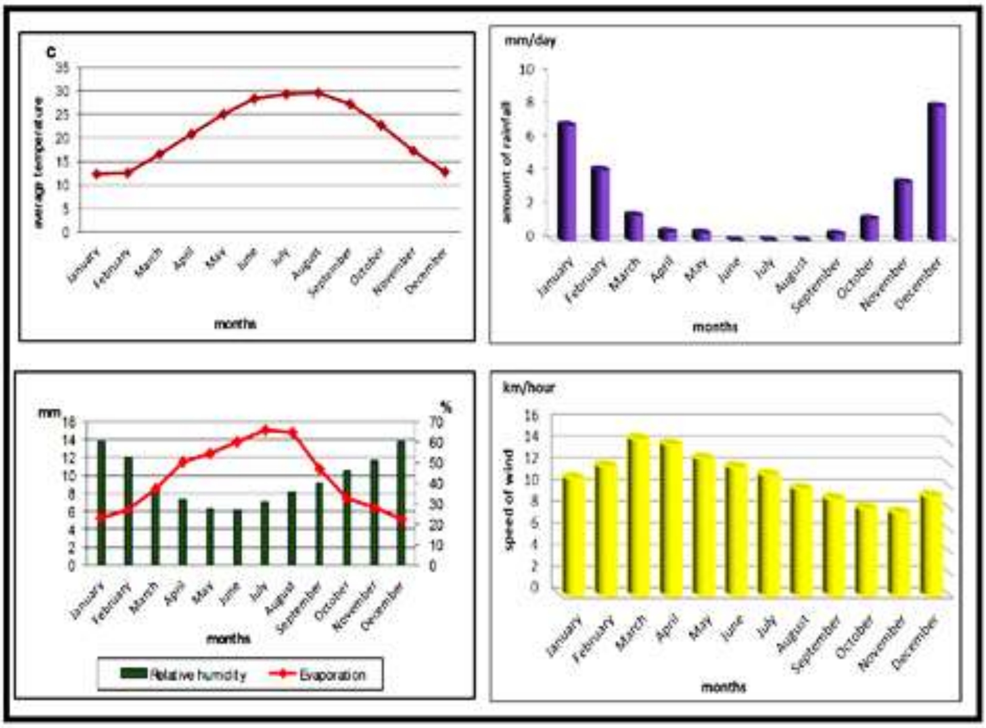
Climatic characteristics play an important role in the emergence and development of wetlands. This is evident through changes in temperature, evaporation rates, and humidity on the one hand, and changes in wind speed and direction on the other hand. This could lead wetlands to deteriorate because it directly affects the water quantities available therein, and hence threatens the biodiversity recorded in the Basin.

As demonstrated in Table 3 and Figure 5, the Basin is climactically distinct in terms of its (a) temperature, (b) rain, (c) evaporation and relative humidity, and (d) wind. These aspects reveal how the wetlands of the Basin are affected by the climate therein. The following remarks are supported further by demonstrating figures and tables to foreground the relevant data.

Table 3: *Some Climatic Characteristics of Siwa Depression*

The month	Average Temperature (C)	Rains (mm/day)	Evaporation (mm/ day)	Relative humidit y (%)	Speed Wind (Km/hour)
January	12.3	6.9	5.3	60.4	10.8
February	12.5	4.23	6.21	52.8	11.9
March	16.6	1.52	8.52	37.7	14.4
April	20.9	0.54	11.52	32.1	13.9
May	25.05	0.47	12.4	27.4	12.6
June	28.4	Zero	13.8	27.2	11.8
July	29.4	Zero	15.1	30.8	11.1
August	29.6	Zero	14.8	35.5	9.8
September	27.1	0.4	10.8	40.3	8.9
October	22.8	1.31	7.5	45.6	8
November	17.3	3.49	6.4	50.8	7.6
December	12.9	8.04	5.14	60	9.12
Anuual average	21.3	26.49	9.8	41.7	10.8

Source: The Egyptian Meteorological Authority, Unpublished Data (1988-2018)



Source: Adapted from Table 3

Figure 5: *Some Climatic Characteristics of Siwa Depression*

- **Temperature Degrees**

Temperature degrees vary within the Basin during seasons and throughout the year. The annual average temperature in the study area is 21.3°C. Lowest temperatures are recorded during Winter, especially in January with an average of 12.3°C. This is attributed to cold winds and rainfall. Temperature begins to slightly rise during Spring as a result of Khamasin thermal lows.

In Summer, temperatures increase to 28.4°C, 29.4°C, and 29.6°C during June, July, and August, respectively. Summer, therefore, is one of the highest seasons in temperatures. This increase of temperatures results in raising water evaporation, which transforms wet sabkhas in the Basin into dry salt sabkhas by salt crusts (see Figure 6). High temperature also affects the growth of natural plants in the Basin inasmuch as it could damage them (see Figure 7).

Source: Field Study (2022)

Figure 6: *Salt Crusts Formation in Wetlands due to High Temperature in Summer*

Source: Field Study (2022)

Figure 7: *Destruction of Some Plants due to High Temperature in Summer*

- **Rains**

Siwa Depression is generally characterized by rain scarcity, as the total annual rainfall there is 26.94mm. Located within the dry desert areas, it has only that kind of sudden showers. The greatest rainfall, however, is recorded in Winter; during December, the rainfall in the study area has been 8.04mm, which is the highest rate recorded to date. Rainfall has reached 6.9mm in January, and 4.23mm in February. The significance of rainfall in the Basin is that it helps form wetlands. This is why when it decreases during Spring or almost vanishes during Summer, it drastically affects the growth of natural plants in the area.

- **Evaporation and Relative Humidity**

Evaporation rate depends on the relative humidity rate and temperatures. The annual average relative humidity in the study area is 41.7%, whereas the annual average rate of evaporation increases up to 9.8mm/day because the area is located within the dry hot desert territory. Relative humidity is at its highest rate in Winter, ranging from 52.8% to 60.4%. It is at its lowest rate in Spring and Summer, as they range from 27.2% to 37.7%. Evaporation rates decrease during Winter, ranging from 4.14 mm/day to 6.23 mm/day. This is caused by low temperatures, rainfall, and high relative humidity that make slat swamps and water bodies spread. Evaporation rates increase during Summer, ranging from 13.8 to 15.1 mm/day, due to high temperatures and low relative humidity. As there is a reverse correlation between evaporation and relative humidity, wetland water evaporates and salt crystals start to appear when evaporation rates increase and relative humidity rates decrease (see Figure 8.1). Likewise, when water evaporation rates increase, the area of some lakes decreases due to the retreat of water up to about 3.2m from the coastline in Winter to the counterpart coastline in Summer in some areas of Augurmi Lake (see Figure 8.2). The thickness of crusts and salt layers on sabkhas and their adjacent lands in the Basin increases too.

1.**Water–Retreat in Augurmi Lake**

2. **Salt Layers Formation**

Source: Field Study (2022)

Figure 8: *Impact of Evaporation Rates Increase on Alzaytun Basin Wetlands*

- **Wind**:

In the study area, the annual wind speed rate is 10.8km/h. The maximum average wind speed has been 14.4km/h in March, while its lowest rate has been 7.6km/h in November. Generally, wind speed rates are high there because the area is flat. On blowing, the wind drifts sand from the surfaces of the low-level areas, and thus leads to the emergence of subsurface water (Azza, 2007). The increase of wind speed makes the drying rates of wetlands and, consequently, wetland salinity rates rise high. The north and northwest winds are the prevailing types of winds in the area (see Table 4). The annual average of the north wind is 12.9%, while that of the northwest wind is 20.1% because of the formation of Khamasin thermal lows that sometimes result in dust storms. The southeast wind is the least blowing wind, with an average of 6.8%. Yet, when it blows, it carves and transports some sandy sediments of those existing in the south of the Basin, and then it deposits these sediments on the surfaces of the nearby sabkhas and on the agriculturally reclaimed lands to the south. This requires human intervention to protect these lands from sand drift (see Figure 9).

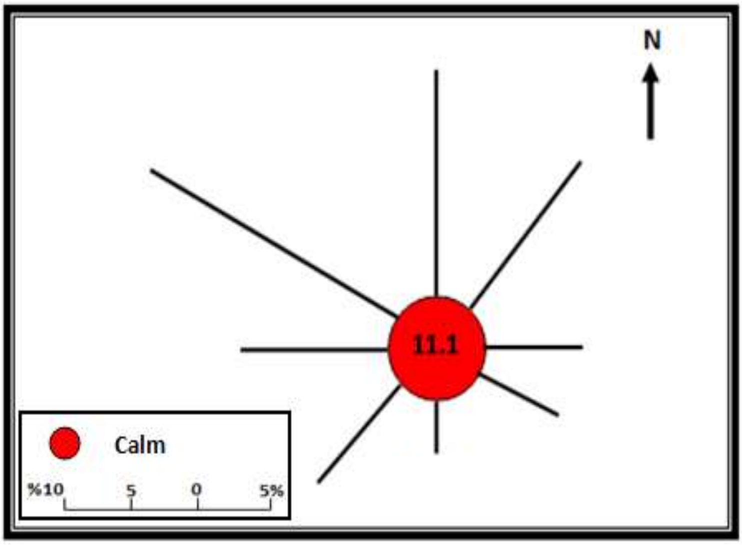
Source: Field Study (2022)

Figure 9: *Means of Protecting the Agriculturally Reclaimed Southern Areas against Sand Drift*

Table 4: *Seasonal Averages and Annual Averages of Wind Directions in Siwa Depression (%)*

Season	N	NE	E	SE	S	SW	W	NW	Calm
Winter	13.4	9.1	6.3	7.8	5.8	11.2	15.2	19.2	8.3
Spring	18.2	14.3	13.9	5.6	3.6	5.9	9.4	18.4	9.8
Summer	9.1	11.2	4.7	10.3	1.3	4.6	8.8	22.2	10.1
Autumn	11.2	15.1	3.8	12.2	3.6	8.2	10.9	20.9	16.3
Average	12.9	12.4	7.1	6.8	3.5	7.4	11.1	20.1	11.1

Source: The Egyptian Meteorological Authority, Unpublished Data (1985-2014)



Source: **Prepared by the researcher**, **adapted from Table 4**

Figure 10: *Wind Rose in Siwa Depression*

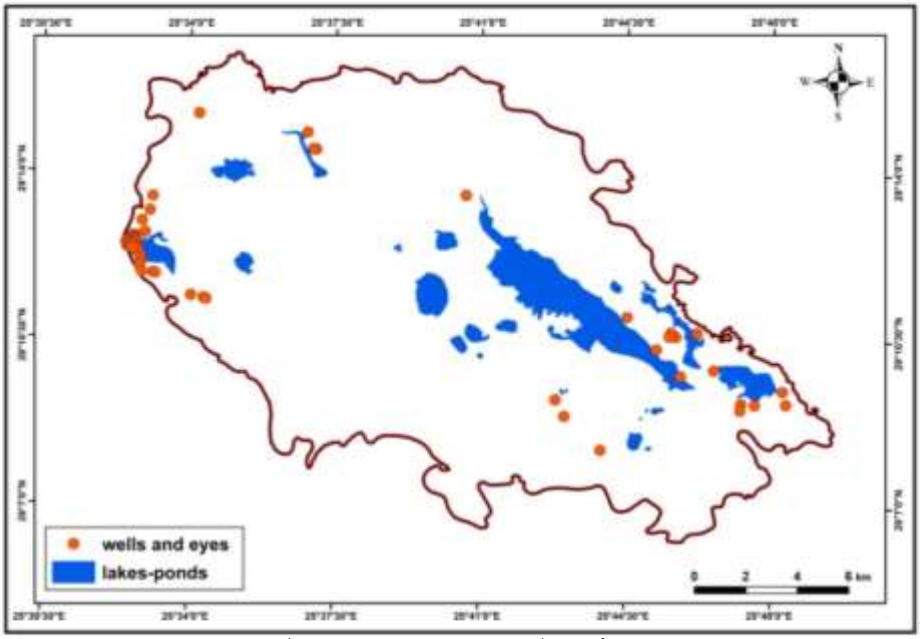
4.1.1.4 Water Sources

Groundwater in aquifers, wells, and natural springs are some of the main sources that provide wetlands with huge amounts of water in Alzaytun Basin, either through the natural rush and overflow of water to the top, or through water ascending by the capillary action to reach the surface layer of the ground. There are about 58 springs and wells in the area (see Figures 11, & 12).

Other water sources for wetlands include the excess drainage water of irrigation and the rainfalls that seep, in proportions, into the soil of the Basin. In Summer, the depth of subsurface water ranges from 0.38m to 1.80m below ground surface, and 0.91m deep; in Winter, it ranges from 0.28m to 1.17m below ground surface, and 0.70m deep (Khader, 2008). This indicates that the average depth of the surface groundwater is comparatively deeper in Summer than in Winter, due to the increase of temperature and the high rates of evaporation in Summer.

Source: Field Study (2022)

Figure 11: *A Natural Water Spring as a Source of Water Replenishment in Augurmi Lake*



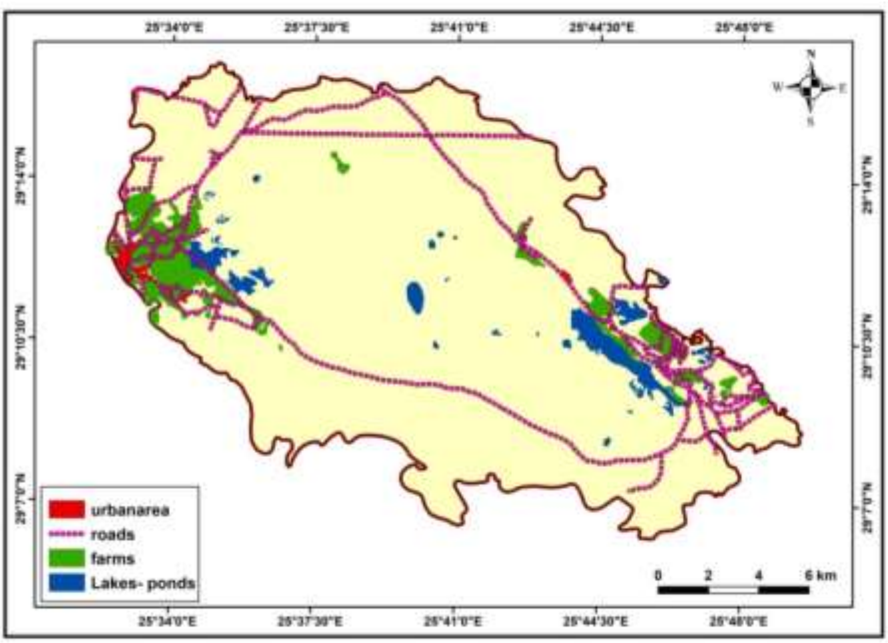
Source: Topographic Maps, at a scale of 1:25000 in 1930, and a scale of 1:50000 in 1996

Figure 12: *Distribution of Wells and Springs in Alzaytun Basin*

4.1.2 Spatial Analysis of Human Environmental Factors

Human interventions are among the factors affecting the natural ecosystem of wetlands. There are some human activities established on some parts of the area, such as planting many agricultural lands, building diverse urban centers and roads, and performing the drying-out operations meant to extract salts from natural salt pans. Wetlands are exposed to many changes, due to these human activities. The human factor is responsible for causing deterioration, change, and even destruction of the components of the biosphere in the area (Saber, 2015). Therefore, it is necessary to identify the changes affecting the area, and how to overcome or reduce their impacts. The human activities in Alzaytun Basin area include the three following hazards.

1. Drying out of lands is brought about by development projects, such as salt extraction, road construction, agricultural reclamation, and urban expansion (see Figure 13).



Source: Topographic Maps, at a scale of 50000:1 in 1996, adapted from Google Earth Pro 2022

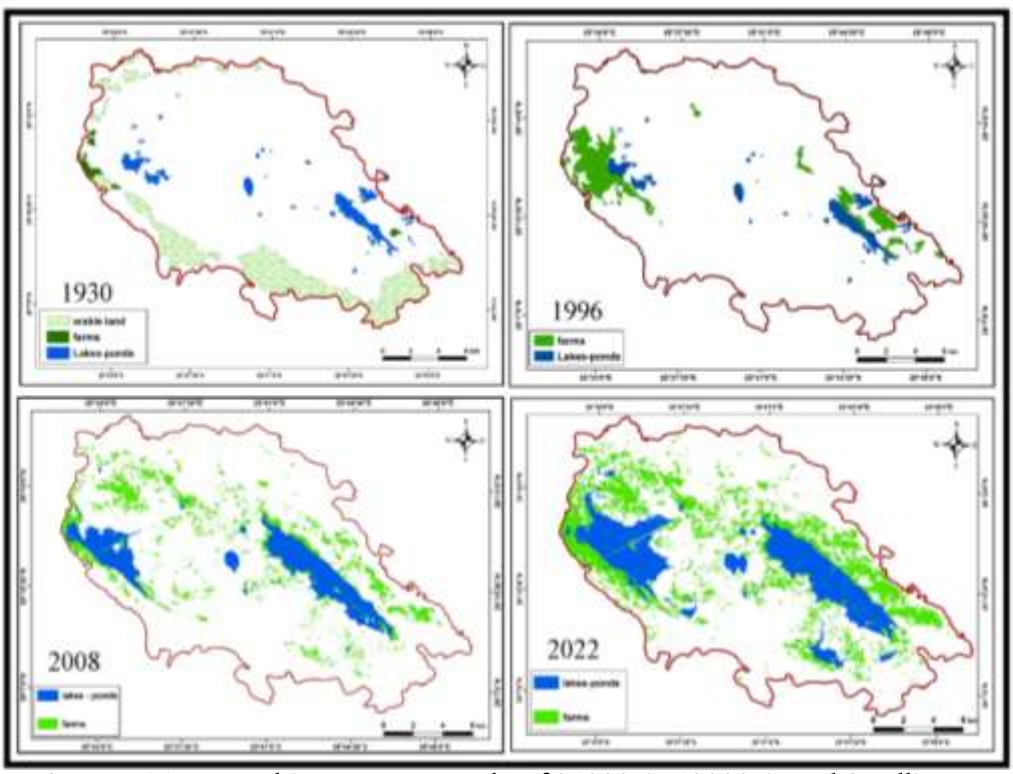
Figure 13: *Human Activities in Alzaytun Basin*

2. Agricultural land degradation results from several factors, including salt accumulation, rise of groundwater level, flood irrigation, overgrazing, and sand drift. Consequently, flood irrigation could cause land "tympany" and water increase that, together, could turn some agricultural lands into wetlands again; overgrazing could result in the loss of soil fertility, the removal of vegetation cover, and the transformation of lands into wastelands; and sand drift could lead to the backfilling of plants.
3. Pollution is caused by various human uses.

Agriculture is the main activity for population. There are several water springs that naturally flow to the top of Alzaytun Basin. There are also many wells (see Figure 14). Therefore, agriculture is one of the most affecting human factors in wetlands of Alzaytun Basin, especially with the agricultural reclamation policy prevailing in Siwa Oasis. By analyzing (Figure 15), it turns out that the area of agricultural lands has increased from 2.2km^2 in 1930 to 15.01km^2 in 1996, with an increase of 12.81km^2; and then it has increased to 17,716km^2 in 2008. Agricultural reclamation has also continued with an increase of 22.5km^2 in 2022. This generally indicates that the residents of the area pay attention to agricultural development.

Source: Field Study (2022)

Figure 14: *Sparkling Springs for Agricultural Land Irrigation in Alzaytun Basin*



Source: Topographic Maps, at a scale of 25000:1, 50000:1; and Satellite Images, derived from Landsat 2008 and Sentinel 2022.

Figure 15: *Planted Lands in Alzaytun Basin*

The crops of date palms, olives, prickly pears, pomegranates, corn, and medicinal and aromatic plants are among the most important agricultural crops in the study area (see Figure 15). In addition, new crops, such as wheat and barley, are also planted to achieve self-sufficiency. The area of agricultural land in Augurmi, west of the study area, is 3,700 acres. In the first place with an area of 1,750 acres comes olive crop, followed by the date crop with an area of 1,300 acres. The area of the remaining crops is, then, 650 acres (Agriculture Directorate in Marsa Matrouh, 2017).

Source: Field Study (2022)

Figure 16: *Some Forms of Crops in Alzaytun Basin*

Based on the above analysis, agricultural development projects in Alzaytun Basin have directly affected wetlands. The increase in the area of agricultural lands has resulted in several factors. In favor of agricultural expansions, the area of wetlands has decreased after backfilling some parts with the use of transported clay soil (see Figure 17). A high increase in agricultural drainage water level, which has been formed by flood irrigation (see Figure 18), has also resulted in huge amounts of water in the soil of some areas; hence, wetlands have appeared, and soil salinity has increased.

Source: Field Study (2022)

Figure 17: *Backfilling of Land with Transported Clay Soil*

Source: Field Study (2022)

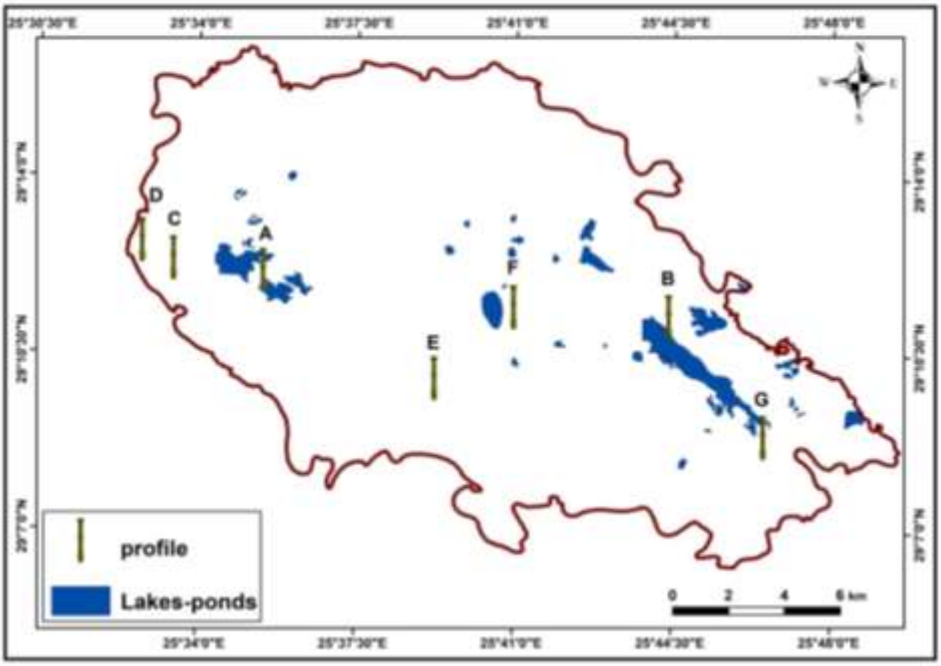
Figure 18: *Agricultural Drains in Alzaytun Basin*

4.2 Analysis of Wetlands Soil Sediments in Alzaytun Basin

Soil is one of the most important natural characteristics affecting wetlands. It controls water retention and/or its transfer to low areas. Therefore, it needs to be studied in detail. This has been done by conducting mechanical, chemical, and mineral analyses of 15 samples from separate sites of wetlands in Alzaytun Basin area (see Figures 19, & 20).

Source: The researcher's Field Study

Figure 19: *Sites of Wetland Soil Samples in Alzaytun Basin Area*



Source: Topographic Maps, at a scale of 1:50000; and Field Study (2022)

Figure 20: *Sites of Wetland Soil Samples in Alzaytun Basin Area*

4.2.1 Volumetric Analysis of Sediments

Volumetric analysis of sediments is that type of analysis that studies the volumetric properties of sample sediments, and represents them with the use of the histogram and the cumulative curve. It is intended to extract some statistical coefficients and classify them into categories, such as those of grain size, sorting coefficient, kurtosis coefficient, and skewness, following Folk and Ward's rules (1957). These functions are exemplified and demonstrated by Tables 5-6-7 and Figure 21.

Table 5: *Mechanical Analysis of Soil Sediments in Alzaytun Basin Area*

No.	Depth cm	Very coarse Sand	coarse Sand	Medium Sand	Fine Sand	Very fine sand	Clay	Soil texture
		1 - 2 mm	0.5 - 1 mm	0.25 - 0.5mm	0.1 - 0.25mm	0.05 - 0.106 mm	Less than 0.05mm	
A1	0-10	29.21	12.72	10.89	18.75	16.74	11.69	Sandy
A2	10-20	14.77	15.60	15.01	25.40	23.45	5.78	Sandy
B1	0-10	13.15	14.65	24.55	30.43	11.01	6.20	Sandy
B2	10-20	8.43	5.74	14.52	41.54	20.55	9.22	Sandy
B3	20-30	13.69	16.70	16.62	24.34	20.09	8.55	Sandy
C1	0-10	29.09	35.01	20.11	13.50	2.28	0.01	Sandy
C2	10-20	27.80	27.04	18.56	17.95	7.88	0.77	Sandy
C3	20-30	20.02	19.84	16.83	23.32	15.99	4.01	Sandy
C4	30-40	15.76	23.99	19.87	20.64	12.43	7.32	Sandy
D	0-10	7.32	19.08	21.13	26.50	16.46	9.51	Sandy

Source: Laboratory Analysis Results of the Natural Characteristics of Sediment Samples from Alzaytun Basin Area.

Table 6: *Phi (Ø) Rates of Soil Sediments in Alzaytun Basin Area*

Sample	Depth cm	Ø 5	Ø 16	Ø 25	Ø 50	Ø 75	Ø 84	Ø 95
A1	0-10	-1.31	-0.9	-0.5	1.3	2.70	3.2	4.0
A2	10-20	-1.28	-0.5	0.1	1.6	2.52	2.8	3.6
B1	0-10	-1.11	-0.35	0.2	1.3	2.25	2.75	3.7
B2	10-20	-1.6	0.5	1.1	2.0	2.80	3.2	3.9
B3	20-30	-1.05	-0.25	0.3	1.8	2.68	3.0	3.8
C1	0-10	-1.3	-1.0	-0.7	0.1	1.00	1.4	2.1
C2	10-20	-1.32	-0.99	-0.65	0.35	1.59	2.1	3.1
C3	20-30	-0.29	-0.77	-0.3	1.09	2.28	2.7	3.7
C4	30-40	-1.2	-0.5	-0.1	1.0	2.20	2.7	3.6
D	0-10	-1.0	-0.89	0.4	1.5	2.60	3.0	3.9

Source: Results of Laboratory Analysis, conducted by the researcher

Table 7: *Volumetric Analysis of Soil Sediments in Alzaytun Basin Area*

No.	Depth cm	Grain Size[4]	Sorting[3]	Skewness[2]	Kurtosis[1]
A1	0-10	1.20	1.83	-0.38	6.96
A2	10-20	1.30	1.56	-3.63	4.84
B1	0-10	1.23	1.50	-0.33	4.04
B2	10-20	1.90	1.51	-5.08	3.83
B3	20-30	1.51	1.55	-3.44	4.73
C1	0-10	0.17	1.12	1.26	2.37
C2	10-20	0.49	1.44	3.02	4.06
C3	20-30	1.00	1.47	2.02	4.22
C4	30-40	1.06	1.53	1.28	4.52
D	0-10	1.20	1.71	-1.98	4.42

Source: Laboratory Analysis Results, conducted by the researcher

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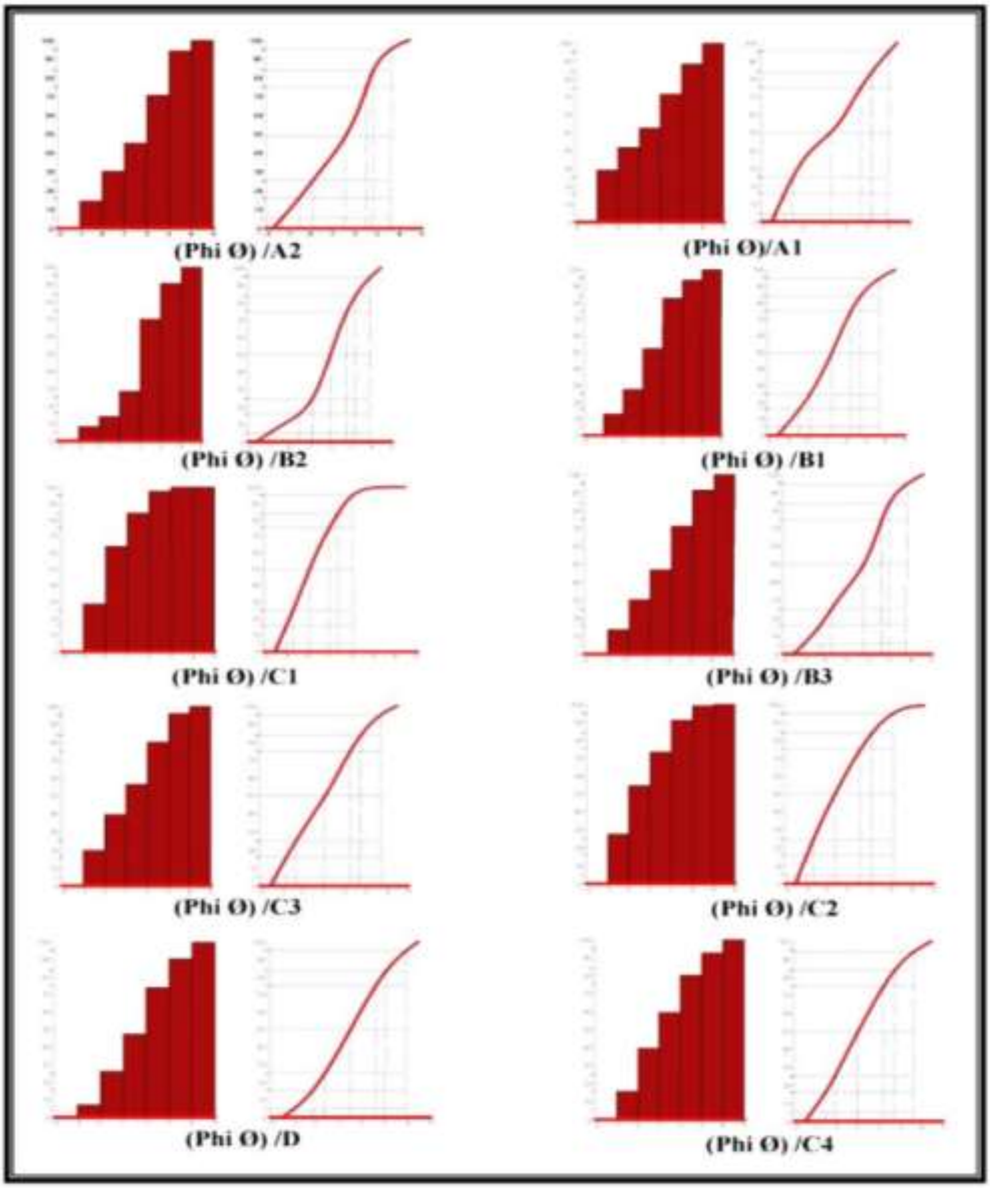
[1] Kurtosis $= \dfrac{Ø95 - Ø5}{2.44\,(Ø75 - Ø25)}$

[2] Skewness $= \dfrac{95\,Ø + Ø5 - 2(Ø50)}{2(Ø95 - Ø5)} + \dfrac{Ø84 + Ø16 - 2(Ø50}{2(Ø84 - Ø16)}$

[3] Sorting $= \dfrac{Ø84 - Ø16}{4} + \dfrac{Ø95 - Ø5}{6.6}$

[4] Grain Size $= \dfrac{Ø16 + Ø50 + Ø84}{3}$

L2*S = Ø ، S =granule diameter/ mm



Source: Adapted from Table 5

Figure 21: *Histogram and Cumulative Curve of Sediment Components in Alzaytun Basin Area*

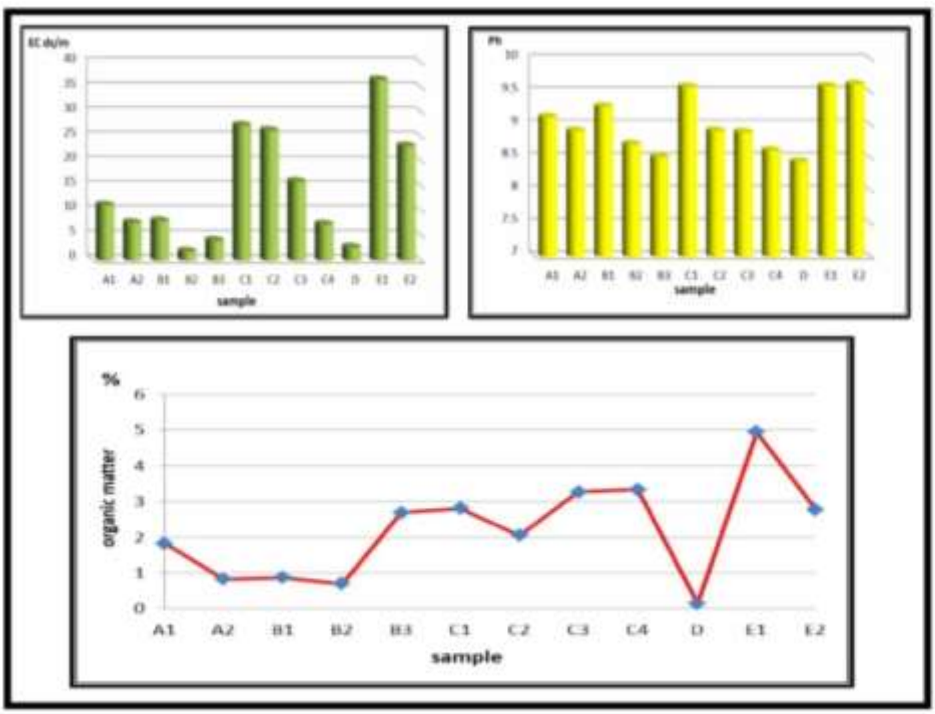
The results of the mechanical analysis in Tables 5-7 and Figure 21 can be summarized in the following points.

- Sands are the most prevalent component of sediments in the area with a percentage ranging from 88.31% to 99.99% of the total weight of the sample. The percentage of silt and clay ranges from 0.01% to 11.69%. Owing to the blowing of winds loaded with Western Desert sands, all soil samples are therefore of a sandy texture. The sandy soil texture, in turn, facilitates the movement and/or rise of groundwater to the top, which makes wetlands spread in the area.
- The soil of the study area consists of coarse and medium sands, and a small amount of silt. This is due to the nearby source of these sands, namely, the Western Desert.
- Sorting values range from 1.83Ø in sample A1 to 1.12Ø in sample C1. This means that the sorting values of sediments are "poor" in most samples. The area sediment samples prove symmetrical in the sorting coefficient, thus indicating that the original substance is the same.
- The values of skewness in soil sediments range from -5.08Ø in sample B2" to 3.02Ø in sample C2, that is, they stand on the extremes of either very negative (i.e., very rough) or very positive (i.e., very smooth). This

indicates that there are sediments of marine and wind origins.

- Kurtosis values of sediments range from a very high kurtosis of 2.37Ø in sample C1 to an extremely high kurtosis of 6.96Ø in sample A1. These values reflect the variation of the original substances of wetland sediments.

4.2.2 Chemical Analysis of Sediments Fig. 22 &Table 8



Source: Table 8

Figure 22: *Salinity, pH, and Organic Matter of Wetland Sediments*

Table 8: *Chemical Analysis of Wetland Soil Sediments in Alzaytun Basin*

No .	Depth cm	pH	PH adjective	EC dS/m	Salinity adjective	Organic % matter	Organic matter adjective
A1	0-10	9.13	Very high	11.32	High	1.83	High
A2	10-20	8.92	High	7.76	Medium	0.82	Low
B1	0-10	9.29	Very high	8.14	High	0.87	Low
B2	10-20	8.72	High	1.95	Not salty	0.70	Low
B3	20-30	8.52	High	4.14	Medium	2.69	Very high
C1	0-10	9.59	Very high	27.52	Very high	2.81	Very high
C2	10-20	8.92	High	26.48	Very high	2.05	Very high
C3	20-30	8.90	High	16.11	High	3.27	Very high
C4	30-40	8.62	High	7.45	Medium	3.33	Very high
D	0-10	8.45	Medium	2.8	Low	0.15	Low
E1	Korchev	9.60	Very high	36.75	Very high	4.94	Very high
E2	Korchev	9.63	Very high	23.32	Very high	2.77	Very high

Source: Laboratory Analysis Results, conducted by the researcher

4.2.2.1 Salinity Degree

Soil salinity is a measure for the percentage of minerals and salts that can be dissolved in water, such as sodium, calcium, potassium, nitrate, and magnesium. The results of the chemical analysis of sediments demonstrate that the percentage of salts ranges from 1.95 to 36.75mmhos. This means that there are two types of salinity. Firstly, non-salty sediments are represented by Sample B2 that is derived from the soil of the agricultural land in the northeast of Alzaytun Lake. It is non-salty because of the soil treatment operations, the acts of backfilling the soil with other clay soils, and the flood irrigation that washes the soil and reduces its salinity. Secondly, highly salty sediments are represented by Sample E1, as they are affected by the high level of groundwater, the increase of water evaporation, and the existence of salts on the surface. In the remaining samples, salinity ranges from medium to high. It is observed that salt sediments are among the features that distinguish the Basin wetlands, especially the sabkhas.

4.2.2.2 pH

Values of pH range from 8.45 to 9.63, that is, from medium alkaline to high alkaline sediments. This percentage negatively affects soil fertility and, consequently, the growth of agricultural crops.

4.2.2.3 Percentage of Organic Matter

The percentage of organic matter in wetland soil ranges from 0.15% to 4.94%, that is, from low to very high percentages. This is due to the high salinity of the soil. It preserves the organic matter in the soil, and slows down its decomposition.

4.2.3 Mineral Analysis

As indicated in Table 9, the results of the mineral analysis show 26 mineral elements in three sediment samples. They can be traced and discussed in the following points.

- The Basin sediments in Samples K3, Z3 and G4 are rich in certain minerals, such as sodium, calcium, magnesium, potassium, iron, and aluminum. Sodium is the most prevalent element with an average of 51613mg/kg, followed by calcium with a concentration ranging from 775.58 to 108024.4mg/kg. This finding proves that the Basin sediments have a high percentage of salts.
- Magnesium concentration ranges from 2725.4 to 21576.5mg/kg, while potassium concentration ranges from 2498.5 to 4890.7mg/kg.
- Iron concentration ranges from 10.4 to 4092.572mg/kg, on account of granitic rocks; aluminum concentration, on the other hand, ranges from 5.55 to 719.327mg/kg because of feldspar.
- Concentrations of minerals, such as arsenic, zinc, strontium, lead, manganese, lithium, indium, gallium, copper, chromium, barium, boron, silver, psyllium, cadmium, and cobalt range from 0.28 to 918.85mg/kg.

Table 9: *Mineral Analysis of Some Sediment Samples from Alzaytun Basin*

Sample					
K3		Z3		G4	
Metal	Concentration average mg/kg	Metal	Concentration average mg/kg	Metal	Concentration average mg/kg
Al	719.327	Al	2,931.63	Al	5.55
Se	N.D	Se	N.D	Se	N.D
V	N.D	V	N.D	V	N.D
Hg	N.D	Hg	0.39	Hg	N.D
Ag	N.D	Ag	N.D	Ag	0.28
B	11.479	B	224.8	B	5.3
Ba	21.19	Ba	22.98	Ba	0.373
Ca	108,024.4	Ca	20,761.3	Ca	775.58
Cd	N.D	Cd	0.4	Cd	N.D
Co	N.D	Co	2.64	Co	N.D
Cr	51.37	Cr	54.56	Cr	2.8
Cu	N.D	Cu	N.D	Cu	N.D
Fe	965.61	Fe	4,092.572	Fe	10.46
Ga	18.36	Ga	9.744	Ga	14.75
In	31.34	In	N.D	In	N.D
Li	2.48	Li	26.57	Li	2.51
Mg	18,745.3	Mg	21,576.5	Mg	2,725.4
Mn	73.2	Mn	102.3	Mn	0.19
Ni	N.D	Ni	N.D	Ni	N.D
Pb	15.19	Pb	5.796	Pb	0.98
K	4,419.03	K	4,890.7	K	2,498.5
Sr	918.85	Sr	68.23	Sr	23.34
Zn	114.4	Zn	78.15	Zn	4.74
As	7.1	As	N.D	As	N.D
Na	48,708.3	Na	49,099.8	Na	57,030.9
Bi	N.D	Bi	N.D	Bi	N.D

Source: Results of Laboratory Analysis, conducted by the researcher

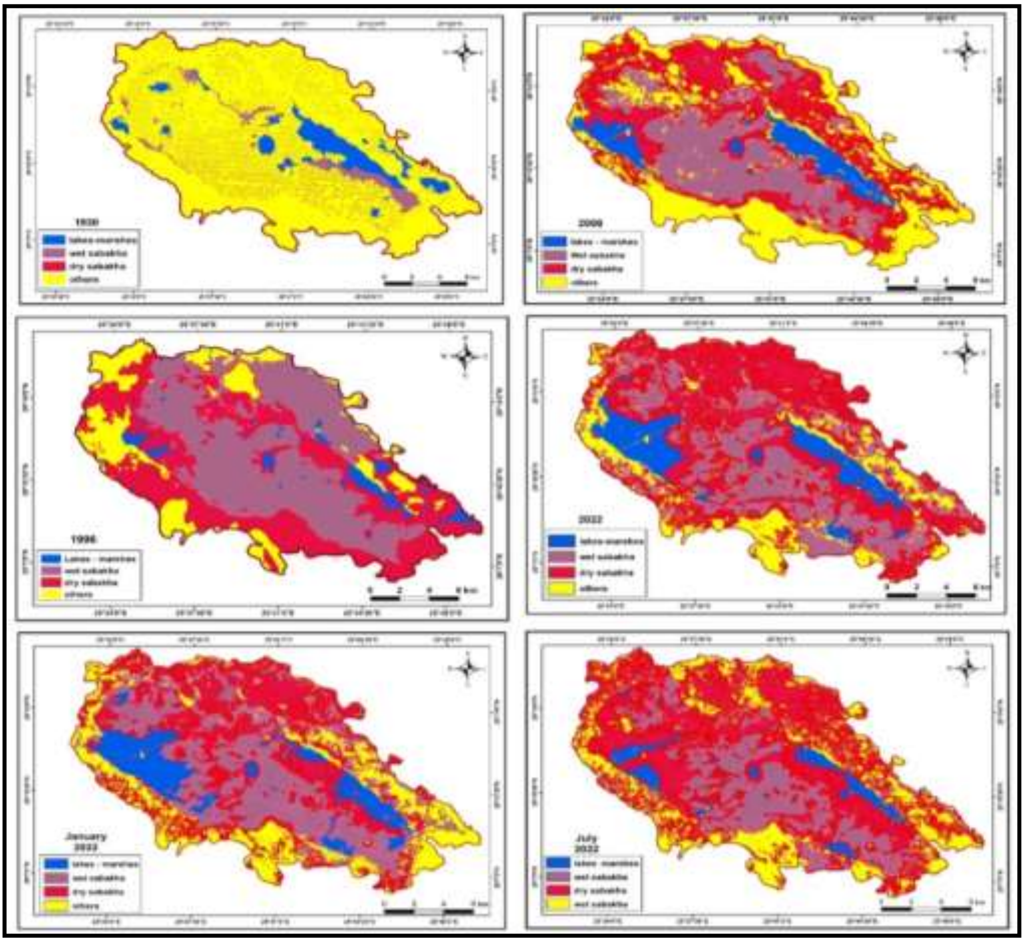
4.3 Detecting the Geomorphological Change in Alzaytun Basin Wetlands

Change detection process is based on comparing satellite images in the way that topographic maps or aerial images have been compared before during different periods of time (Motamed, 2008). The resent study is meant to compare topographic maps and satellite images of different years. The results have indicated that the area of Alzaytun Basin wetlands, along with their features, is constantly changing. The following is a study of the most important geomorphological features of Alzaytun Basin wetlands (see Figure 23 & Tables 10-11).

Table 10: *The Area of Alzaytun Basin Geomorphological Features*

Features	1930		1996		2008		2022	
	area/ km^2	%	area/ km^2	%	area/ km^2	%	area/ km^2	%
Lakes and Marshes	21.2	7.04	21.34	7.09	23.958	7.96	32.54	10.81
Wet sabakha	11.3	3.75	117.11	38.91	87.416	29.04	84.91	28.21
Dry sabakha	4.5	1.5	112.24	37.3	102.535	34.06	123.53	41.04
Others	264	87.71	50.31	16.7	87.091	28.94	60.02	19.94
Total	301	100	301	100	301	100	301	100

Source: Adapted from Figure 23, using Arc Map 10.6.1



Source: Topographic Maps, at a scale of 1:25000 in 1930, and a scale of 1:50000 in 1996; and Satellite Images

Figure 23: *Annual and Seasonal Geomorphological Changes (1930-2022)*

Table 11: *Changes in Wetlands during Summer and Winter (2022)*

Features	Area/km2(2022/1)	%	Area/km2(2022/7)	%
Lakes and Marshes	35.70	11.87	15.40	5.12
Wet sabakha	106.1	35.25	61.70	20.51
Dry sabakha	108.11	35.92	157.817	52.41
Othres	51.09	16.96	66.083	21.96
Total	301	100	301	100

Source: Adapted from Figure 23, using Arc Map 10.6.1

The data introduced in Tables 10-11 and Figure 23, elicited through a careful detection of the geomorphological changes in the Basin, can be explained in the following three subsections. The first is concerned with lakes and marshes of the Basin wetlands. The second is dedicated to sabkhas, distinguishing between wet and dry types, with a particular focus on the marked formations of the latter. The third attends to the other significant features noticed in the study area.

4.3.1 Lakes and Marshes

In 1930, the area of lakes and marshes has been 21.2km^2, representing 7.04% of the total area of the Basin, while its area has amounted to 21.34km^2 in 1996, representing 7.09%. In 2008, it has reached 23,958km^2, recording 7.96% of the total area. Now, in 2022, its area is 32.54km^2, representing 10.81%. This indicates that this area is constantly increasing during the respective period. This is due to the agricultural reclamation in the region, which has led to an increase in, firstly, the drainage rates resulting from irrigation and, secondly, the level of water in the soil and, consequently, its leakage from the agricultural lands to the areas of lakes, swamps, and marshes. Remarkably, the area of lakes and marshes has seasonally changed in 2022, as there has been a 20.3km^2 decrease in their area from 35.7km^2 in Winter (viz., January) to 15.4km^2 in Summer (viz., July), as a result of the extreme rise in temperatures and evaporation rates.

4.3.2 Sabkhas

Sabkhas are an important geomorphological feature in Alzaytun Basin area. They are common in the low-lying coasts, and in the lower interior lands close to groundwater (El-Tohamy, 2014). A sabkha is defined as a (marine, underground, or surface) water system, or a (floody or air) continental system, consisting of salt deposits mixed with originally-transported sediments, organic remains, and evaporative and non-evaporative sediments (Ismail, 2007). Deemed as an important source of water for sabkhas, groundwater in Alzaytun Basin proves essential in the emergence of sabkhas there. The sabkhas in Alzaytun Basin are classified into two types, namely, wet and dry, as analyzed below.

4.3.2.1 Wet Sabkhas

From 1930 to 1996, the area of wet sabkhas has increased to 105.81km^2 as a consequence of the rise of groundwater level, and the upward flow of water resulting from natural springs. In 2008, wet sabkhas have been 87.416km^2 in area, representing 29.04% of the total area. This records a 29.694km^2 decrease from its previous area in 1996, and a slight decrease of 2,506km^2 in the period from 2008 to 2022. This is caused by drying out acts and such human interventions as road construction and agricultural reclamations. A seasonal change is also marked in 2022, when the area of wet sabkhas has decreased by 44.4km^2, that is, from 106.1km^2 during Winter (viz., January) to 61.7km^2 during Summer (viz., July), on account of the increase of evaporation rates in Summer.

4.3.2.2 Dry Sabkhas

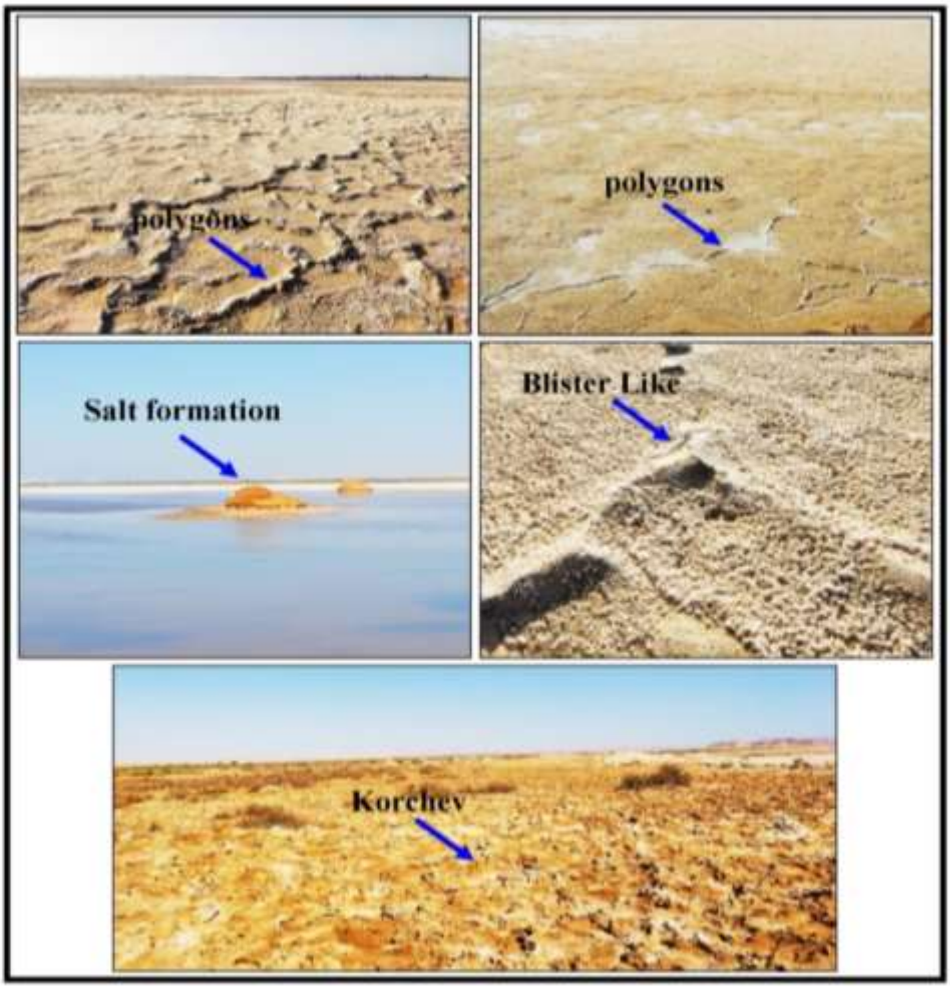
In 1930, the dry sabkha has been 4.5km^2 in area, representing 1.5% of the total area; in 1996, it has reached 112.24km^2, representing 37.3%. This indicates that this area, which is one of the stages of wetland development in the Basin, has significantly increased by about 109.3km^2 during that period. This has occurred because of high temperatures and evaporation rates. Thus, large parts have become salt basins that have been thereafter used for salt extraction. In 2008, the area of sabkhas has decreased to 102.535km^2, representing 34.06%, which signifies a comparatively 9.705km^2 decrease from its previous area in 1996. This is all caused by human activities, such as road construction, urban development, and land reclamation.

In 2022, the area of dry sabkhas has increased to 123.53km^2, representing 41.04% of the total area. Their area has also seasonally changed, as it has increased from 108.11km^2 during Winter (viz., January) to 157.817km^2 during Summer (viz., July), recording a 49.707km^2 increase in area. This is due to high temperatures and evaporation rates that have led some areas of wet sabkhas and marshes into dry sabkhas.

Owing to the flat surface that has helped in the emergence and development of these sabkhas, many subtle features have also spread on the surfaces of Alzaytun Basin sabkhas (see Figure 24). Such features give a distinctive morphological appearance to the sabkha. Among the most important forms of dry sabkhas are the four following types.

- **Salt Polygons**

  Salt Polygons are the most common form on the surfaces of sabkhas in the study area (see Figure 24). They vary across regions; they could be triangular, quadrilateral, or pentagonal in shape. Their height ranges from a few millimeters to centimeters. Their edges are characterized by some bends, such as protrusions and salt bumps. They tend to be white, indicating the presence of halite salt in large proportions. There is a strong correlation between high edges of salt polygons and the proportion of salts: the higher the proportion of salts in the sabkha, the greater the prevalence of salt polygons. Dehydration factors, caused by high temperatures and evaporation rates, expose the outer layer of sabkha surfaces to cracks of different dimensional salt polygons. The rise of water level to the surface, along with the increase of water evaporation rates and the deposition of salts on the surface of sabkhas, has also led to the rise of polygon edges, as common as it is in the sabkhas around Augurmi Lake, Alzaytun Lake, and Quraysht Lake.



Source: Field Study (2022)

Figure 24: *Diversity of Micro-Geomorphological Features of Sabkhas in Alzaytun Basin*

- **Blisters**

Blisters, in the shape of a dome, are among the most important fine forms on the surfaces of sabkhas (Figure 24). In the study area, they are formed above the surfaces of salt crusts, and their shape is associated with the shape of salt polygons. They are incompletely formed prior to the formation and growth of the respective polygons.

- **Salt Formations**:

Salt formations are solidified formations of salt, formed as a result of high temperatures and evaporation rates, and drought. This process takes place throughout successive periods. They consist of salt deposits with few fine sandy sediments (see Figure 24).

- **Korchev**

Korchev feature is one of the formations on the surfaces of wetlands, especially in sabkhas. It consists of different wrinkles in the surface due to the expansion resulting from the dry upper salt layer (Aql, 2003). It is a deposit of salt mixed with fine sand and clay, caused by high temperatures and evaporation rates in Summer (see Figure 24). Given the hardness of korchev, it is used for making the stones, with which traditional houses are built.

Generally, salts accumulated on the surfaces of sabkhas stand as the first stage in the salt weathering circle. In the beginning, the wind disperses salts in the form of salt dust, filling the cracks and joints between the pores of the soil. Then, it deposits them on the facades of the nearby buildings. This results in the activity of salt weathering processes.

4.3.3 Other Features

There are some other features in the area, such as sandy scopes and the human activities established on some parts of wetlands, including agricultural lands, residential communities, and roads. These features have occupied an area of 264km^2 in 1930, representing 87.71% of the total area of the region. The largest part of this area is occupied by sandy scopes. This area has thereafter decreased to 60.02km^2 in 2022, representing 19.94%, due to two factors. Firstly, the rise of the groundwater level and the rise of water to the top have resulted in transforming areas of sandy scopes into wetlands, such as lakes, marshes, and sabkhas. Secondly, residents' increasing interest in development has led to reclaiming large areas of the Basin for purposes of agriculture and road construction.

4.4 The Quality of Wetlands

Wetlands are rich in resources and potentials. To assess and improve their quality, their available environmental resources must be identified to recognize their capacity for current and future human uses as much as possible. Thus, raising environmental awareness and developing plans for managing wetlands are necessary to serve the sustainable development goals. Field studies and literature, such as Saber (2015), Motamed (2008) and Khader (2008), have significantly contributed to the discussion of the quality of wetlands in a manner that foregrounds their significance. The two following subsections highlight this.

4.4.1 Environmental Significance of Wetlands

Wetlands are a distinctive morphological feature in Alzaytun Basin because of their ecological and biological roles in preserving the environmental balance within the Basin. Therefore, they need to be protected, and their ecological characteristics need to be preserved and optimally exploited for the benefit of humanity. Among the most important environmental resources are the following.

- Wetlands are important ecosystems because of their significant role in maintaining the vital ecological balance. They are also distinguished by their attractive natural beauty.

- Alzaytun Basin wetlands are known for their biodiversity of salt-tolerant natural wild plants, such as Flora, Reeds, Zygophyllum, Halfa, Glassworts, Juncus Acutus, Tarfas (viz., Tamarix), and El-Hatab (viz., Tamarix arborea Ehrenb). Most of these plants are used for therapeutic purposes and in some other industries. Therefore, these rare plant species need to be protected (see Figure 25).

Source: Field Study (2022)

Figure 25: *Natural Plants in Alzaytun Basin Area*

- Wetlands provide a suitable environment for some wild birds—such as hippolais, pintail, and common chiffchaff that prefers to migrate to Siwa Oasis for dates—and some wild animals, such as mammals.
- Wetlands purify and filter the water passing through them, and thus store large quantities of water to feed the aquifers.

Wetlands has an important role in getting rid of chemicals and heavy elements from water. Algae and aquatic plants absorb some pollutants too (Environmental Affairs Agency, 2008).

4.4.2 Economic Significance of Wetlands

The dry and heat nature of Alzaytun Basin directly affects the economic activity in wetlands. Recently, attention has been paid to this area to economically exploit it in many activities as follows.

- Notable for being the main source of the best and finest salts in large proportions for both local use and exportation to European countries, salt ponds in Alzaytun Basin are famously called the White Gold Mines (see Figure 26).

Source: Field Study (2022)

Figure 26: *Salt Extraction in Alzaytun Basin Area*

- Salt ponds in Alzaytun Basin can be used for purposes of medical treatment tourism. They are an important source of national income. They are attractions for tourists who come to enjoy swimming in order to relax, reduce negative energy, and treat some skin diseases, such as psoriasis and eczema.
- Ecotourism contributes to flouring and developing tourism in the study area. Alzaytun Basin has impressive natural resources that make the area one of the major tourist attractions in the Western Desert. Such features as lakes, salt ponds, and natural springs, which are used for swimming and treatment purposes, distinguish the area (see Figure 27).

Source: https://visit.guide/ar/article/water-springs-in-siwa

Figure 27: *Use of Salt Ponds for Relaxation and Treatment of Some Diseases*

- Wetlands are among the main sources of fish, so the General Authority for Fish Resources Development seeks to develop fish wealth in Siwa Oasis by carrying out fish farming projects and providing them with large amounts of baby saltwater fish, such as mullet and red tilapia. However, the area has not provided the expected fish production as yet, but it seeks to develop its quantities in the future.
- Alzaytun Basin area is known for mineral water bottling industry, which is a major source of income for residents. It is common there due to the abundance of natural water resources, especially groundwater that

is among the purest water sources and that does not need any treatment because of its high temperature on being extracted from deep wells.

5. Results and Recommendations

Various and remarkable are the results of the present study. They are based on the four approaches of the analysis, but with an emphasis on their interrelated connections and their direct and/or indirect responses to the objective of the study. They can be singled out in the following points.

- Wetlands in Alzaytun Basin are 240.98km^2 in area, of which 32.54km^2 are for lakes and marshes, 84.91km^2 are for wet sabkhas, and 123.53km^2 are for dry sabkhas.
- Groundwater, wells, and natural springs, which are the water sources in Alzaytun Basin, feed wetlands therein.
- Moghra formations, dating back to the Eocene era, and surface sediments, dating back to the Holocene era, are among the geological formations in the area.
- Climatic characteristics play an important role in the emergence and development of wetlands through changes in temperatures, evaporation rates, and humidity on the one hand, and changes in

wind speed and direction, on the other hand. High temperatures in Summer cause water evaporation, deposition of salts on the surface, and transformation of wetlands to dry sabkhas; whereas low temperatures in Winter and the increase of groundwater level make soil preserve huge amounts of water, and consequently help large areas of wetlands emerge.

- Agriculture is the main activity for people there. In 2008, the area of the agricultural lands has increased to 17,716km^2. Agricultural reclamation has continued until it has reached an area of 22.5km^2 in 2022.
- Due to human interventions in favor of such development projects as land reclamation, road construction, and urban growth, some parts of wetlands have deteriorated.
- The area is known for biodiversity, including both salt-tolerant natural wild plants used for therapeutic purposes and in some industries, and wild birds and animals, such as mammals.
- As for sediments in the area, sand is the most common form of sediments. It is rich in high salinity and alkalinity, and organic matter. This is due to the high salinity of soil that preserves the

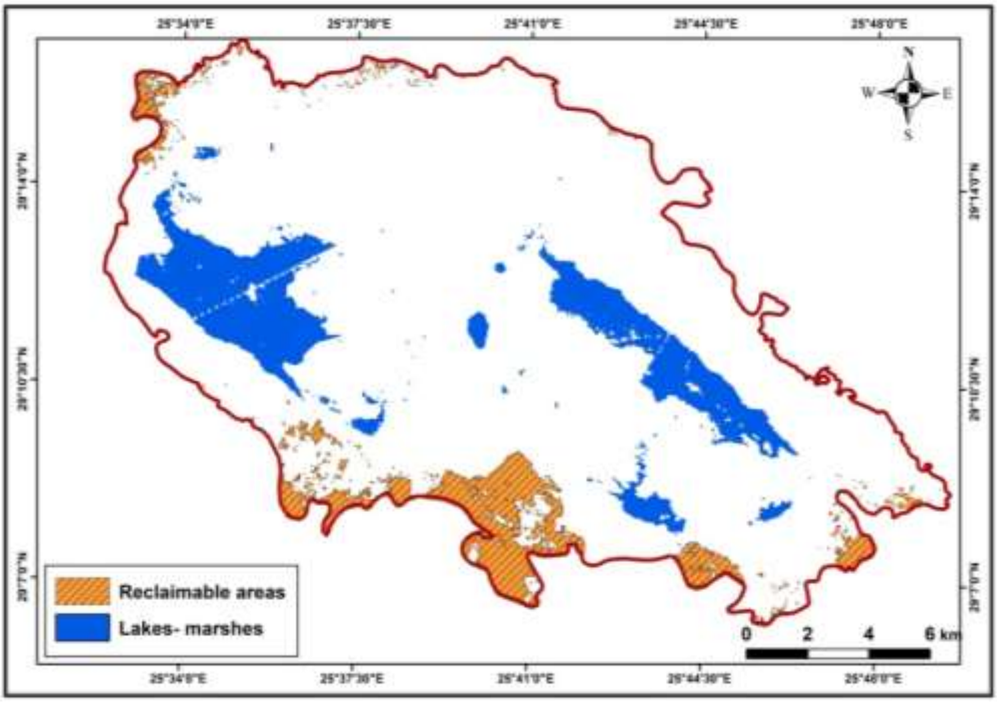
organic matter in soil and slows down its decomposition. Sand is also characterized by minerals, such as sodium, calcium, magnesium, potassium, iron, and aluminum.

- It is worth mentioning that the area of wetlands and their features is constantly changing in Alzaytun Basin during various periods (1930-2022), due to climate factors and human interventions.
- Common on the surface of Alzaytun Basin sabkhas are many subtle features, such as blisters, slat polygons, and korchev.
- Celebrated as the main source of the best and finest salts in large proportions for both local use and exportation to European countries, salt ponds in Alzaytun Basin are famously known as the White Gold Mines.
- Remarkably, Alzaytun Basin has spectacular natural resources that make the area one of the foremost tourist attractions in the Western Desert, and thus help in achieving the desired tourism development.

Promising though the list of results is, it uncovers the need to change some situations and/or practices that threaten the geo-environmental features of wetlands in general, and those of Alzaytun Basin in particular. The society, represented by individuals and authorities, should cooperate to preserve and/or maintain the area lest it deteriorates or, even, disappear. This is why the following concluding **recommendations** seem reasonable, if not urgent, to be adopted and carried out.

- Damaged wetlands need to be protected, and some parts thereof can be transferred into natural reserves.
- It is also necessary to protect the natural resources of the environment from all kinds of pollution.
- Laws of protecting wetlands from all dangers should be applied, and constant attention needs to be paid.
- Moreover, it is required to conduct scientific studies to identify the capacity of wetlands for human activities and optimal use in all development projects.
- It is essential to reduce the risks of salt weathering in the area through undertaking some scientific analyses of the soil before using it, for the purpose of determining the most suitable regions for diverse human uses, especially those of the agricultural expansion, without environmentally abusing wetlands themselves.
- Natural resources in wetlands need to be constantly maintained the same way as the drying out of lands should be reduced. Land reclamation needs to be concentrated in the southern, southeastern, northern and northwest regions within the sandy

scopes of the Basin in order to preserve their natural shape without damaging it (see Figure 28).



Source: Satellite Image, derived from Sentinel-2 (2022)

Figure 28: *Most Suitable Areas for Sustainable Developments in Alzaytun Basin*

- Sabkhas need to be optimally used in extracting types of salts (e.g., halite salt, & sodium chloride) for their great economic importance.
- Roads should be designed to be higher than the level of wetlands, especially sabkhas, in order to avoid risks of salt weathering. Roads also need to be periodically maintained in order to avoid

continuous disintegration and/or chemical decomposition.

- Improving tourist resorts and providing development projects with the necessary infrastructure and services are necessary to develop the tourism sector.
- There is a necessity to establish fish farms in the lakes of the study area, especially in Augurmi Lake, and to provide all the supplies necessary for fish wealth development.
- Finally, providing the trained work force and paying attention to transportation roads are the main factors for carrying out these tentative recommendations.

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