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# Integration of Remote Sensing and GIS with Sedimentological and Chemical Investigations for Environmental Evaluation Of Al Uyoun Evaporation Lake, Al Hassa, KSA

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**Abstrac:** Al Uyoun Evaporation Lake is a wetland located to the north of Al Hassa Oasis, eastern province, KSA. The water of this lake is originated from the excess of drainage water which collected by earthen drainage network and discharged into the lake. Wetlands are important link between water and land ecosystems. They provide habitats and refuges for wildlife, flood protection and contribute to abatement of impact of pollution and promoting groundwater recharge. The main morphologic features of Al Uyoun Lake area are wetlands, sabkhas and sand dunes. Salt tolerant vegetation (halophyte) is found in some of the less salt affected sabkha areas. The present paper aims to study the environment of Al Uyoun Lake through integration of remote sensing and geographical information systems (GIS) coupled with Sedimentological, hydrogeological and chemical investigations. A complementary objective of this study was to demonstrate the GIS capabilities in exploring the full value of environmental data through spatial analysis and visual display of geographic information. The processed landsat-5 TM & SPOT Imageries indicated that, there were changes in areal extensions of both inland sabkha and water ponds with time. The origin and the various sediments types and their statistical grain size parameters were elaborated. Through chemical analyses, the major and minor ions content of soil pore water, surface water and sabkha soil samples were assessed. Then the GIS was used to facilitate: assessment of the impact of the extensions of inland sabkhas on the fertile soils of Al Hassa Oasis, water quality of Al Uyoun Lake and the potentiality of reusing its water for agricultural purposes and for irrigation water management at this vital area. Significant recommendations towards, improving the efficiency of water management, reuse of wetland water for agricultural purposes, mitigation of the impacts of the expansions of inland sabkhas surrounding Al Hassa Oasis and the sustainable development plan of Al Hassa Oasis, were given.

**Key words:** *Remote sensing · GIS · Wetlands · Soil Chemistry · Grain Size analysis · Al Uyoun Lake · Al Hassa Oasis · KSA*

## INTRODUCTION

Al Hassa Oasis is one of the largest natural oases of the world and one of the main and old agricultural centers in the Kingdom of Saudi Arabia. Al Hassa Oasis is located 70 km west of the Arabian Gulf (Fig., 1). The oasis is irrigated from groundwater discharging from the underlying aquifers through an irrigation network of concrete canals. Al Hassa drainage water is collected by 1641 earthen lateral open canals having depths of about 1 m. The collected drainage water in the eastern sector of the oasis flows from the laterals to three sub main drainage canals which are connected to main drainage canal D2 (Fig, 2). The collected water in this drainage flows towards an evaporation lake at 13 km to the east of Al Hassa Oasis. The drainage water in the northern sector flows from the laterals to six sub main drainage canals which are connected to main drainage canal D1. Drainage water in D1 flows towards an evaporation lake outside Al Hassa Oasis, 52 km north of Al Hofuf. The water remains in the evaporation lakes during winter season to be used to supply cattle with drinking water and for aquifer recharge. From December until April each year, the agricultural drainage water overflows from the northern lake through small waterways into the Arabian Gulf, [1].

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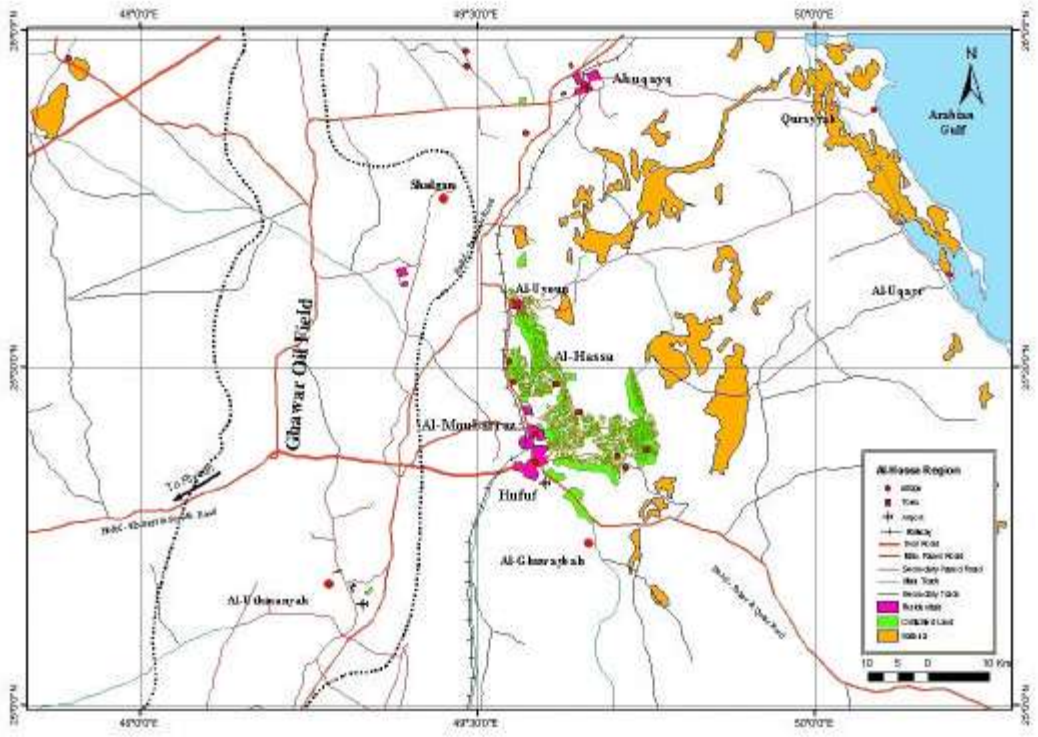


Fig. 1: Base map of Al Hassa Region and the location of the study area.

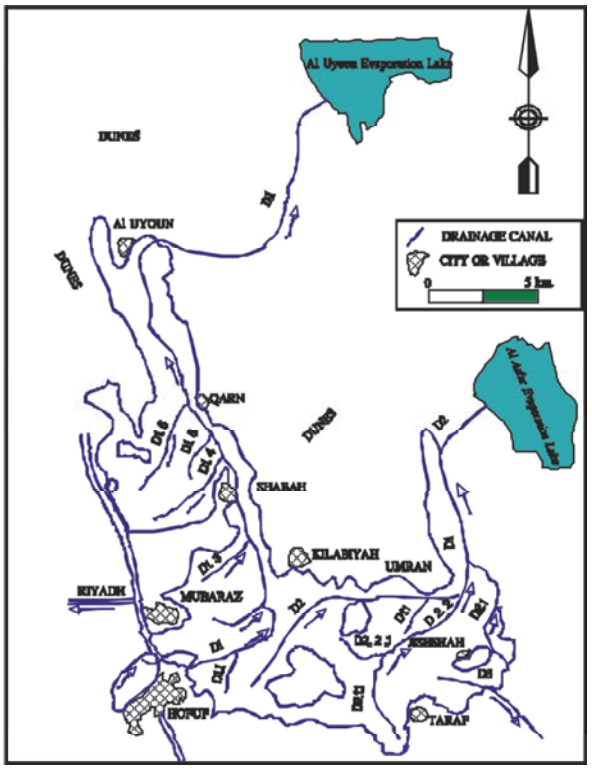


Fig. 2: Main Drainage System of Al Hassa Irrigation and Drainage Project.

Wetlands are important link between water and land ecosystems. They provide habitats and refuges for wildlife, flood protection and contribute to abatement of impact of pollution and promoting groundwater recharge. The main salient morphologic features of Al Uyoun Lake are wetland, sabkhas and sand dunes. Salt tolerant vegetation (halophyte) are found in some of the less salt affected sabkha areas.

In desert environments sabkha is one of the least investigated environments. That is most probably due to its subtle nature. However, due to its potential economic value and/or its direct or indirect impact on the environment;

Particularly, groundwater, interest in sabkha deposits increased in recent years. Information on the location and area of various grades of sabkha will provide valuable information about these phenomena and to know its environmental impacts on the surrounding areas and to investigate its dynamics. The Eastern province of Saudi Arabia has many sabkha; the coastal sabkha has been studied by many workers [2-4].

A very distinct vegetation type which occurs at both inland and coastal sabkha is the Phoenix dactylifera/Tamarix sp type. These sites are highly valued by people seeking recreation because they provide shade

and green, otherwise non spectacular landscape. Generally there are much more locations along the sabkha edges where the environmental conditions would support Phoenix/Tamarix communities. It was strongly suggested that these communities could be cultivated in order to provide more recreational possibilities especially near urban settlements [4].

Hydrogeology and hydrochemistry of Al Hassa area have been reported in a number of studies [5-10].

The present paper aims to study the environment of Al Uyoun Lake. Remote sensing, Sedimentological, hydrogeological, chemical studies and Geographical Information Systems (GIS) are implemented to achieve the objectives of this study.

## MATERIALS AND METHODS

Multi-date Landsat-5 TM imageries of the years 1987, 1993, 1998 and 2000 and SPOT imageries of year 2007 of the study area had been processed and analyzed to investigate the dynamics of both water ponds and the associated sabkha with time at Al Uyoun Lake area. Ninety five surface soil samples representing each soil series from Al Uyoun sabkha were collected. The sampling of sabkha was sometimes hindered by small water ponds or local vegetations. Thirty five samples from surface water and from the isolated water ponds and eight samples of soil water from the area which was characterized by shallow water table (˜20 cm depth) had been collected in March and April, 2008. The latitude and longitude of the soil and water samples coordinates were measured using high accuracy differential GPS. The soil samples were collected from pits 20 to30 cm deep. The soil samples were then air dried, grounded and sieved through a 2 mm sieve. A paste in deionnized water was prepared and filtered. The water extracts were obtained and tagged for Sedimentological and chemical analyses. The grain size distribution had been determined using the Granular Composition Test Set with sieve shaker and standard set of sieves for dry and wet sieving. The granular composition of the representative sample was obtained by applying an electromagnetic sieve shaker. The sieve shaker keeps the sample continuously in motion in order to obtain the best possible sieving results. The pH and total soluble salts were measured in the soil paste extract [11]. Sodium and potassium was determined by flame photometer according to Jackson [12]. Calcium and magnesium were determined by atomic absorption spectrophotometer according to Carter [13]. Soluble carbonates and bicarbonates were determined volumetrically in the soil paste extract by titration against 0.01 N Hydrochloric acid using phenolphthalein and methyl orange as indicators according to Jackson [14]. Soluble chlorides were determined by titration with 0.01 N silver nitrate solution and potassium chromate as indicator according to Richards [15]. Sulphate was determined by metrically turbid with barium chloride method as described by Jackson [12]. Organic matter content was determined according to Walkley-Black rapid titration method [14]. The concentrations of $NO_3^-$ were determined in soil paste extract and water samples according to Norman *et al*. [16] method. Satellite images were processed using ERDAS Imagine software. ArcGIS software was used for the integration of interpreted satellite images and the output parameters and for visualizing their spatial distribution.

## RESULTS AND DISCUSSIONS

**Remote Sensing Investigations:** Landsat -5 TM imageries with seven bands of Years 1987, 1993, 1998 and 2000 beside SPOT imageries of year 2007 of the Al Uyoun area had been geo-referenced, visually analyzed and interpreted to identify different geomorphic units of Al Uyoun Lake environment. The digital elevation model (DEM) of the study area was also generated and analyzed. The Elevation Data collected using the GPS system has been used for constructing a DEM for Al Uyoun area (Fig. 3). This map facilitated the interpretation of the result of the grain size distribution and the result of the chemical analysis. From this map it is noticed that the elevation of Al Uyoun is decreasing toward east and it ranges from 80 m above sea level (asl) in the west to 55 m asl in the east.

The processed Landsat-5 TM and SPOT imageries (Fig. 4) indicated that, there is a general shrinking in both sabkha and wetland areas with time, as they were compared in 1987, 2000 and 2007. This could be attributed to the water of Drain one (D1) which is recycled by Hassa Irrigation and Drainage Authority (HIDA). Sabkha spectral signature in imagery taken at different wavelengths is complex. It is related to salt content in soil, low relief, moisture content, groundwater table, surface water in sabkha areas, salt tolerant halophytic vegetation, texture, color and composition of soil and soil profiles. However, different sabkha grades were recognized. These different sabkha grades had various degrees of salt content as it was indicated from the TDS spatial distribution map gained from the chemical analysis of this study.

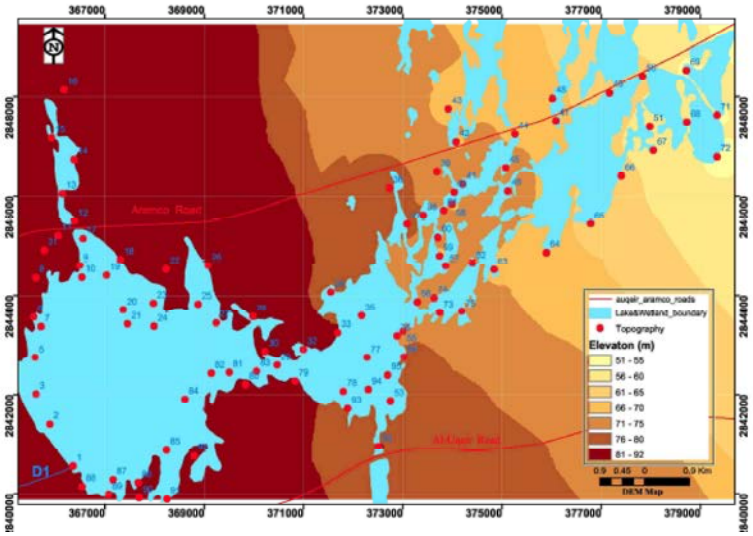


Fig. 3: Digital Elevation Model Map of Al Uyoun evaporation lake area, Al Hassa, KSA.

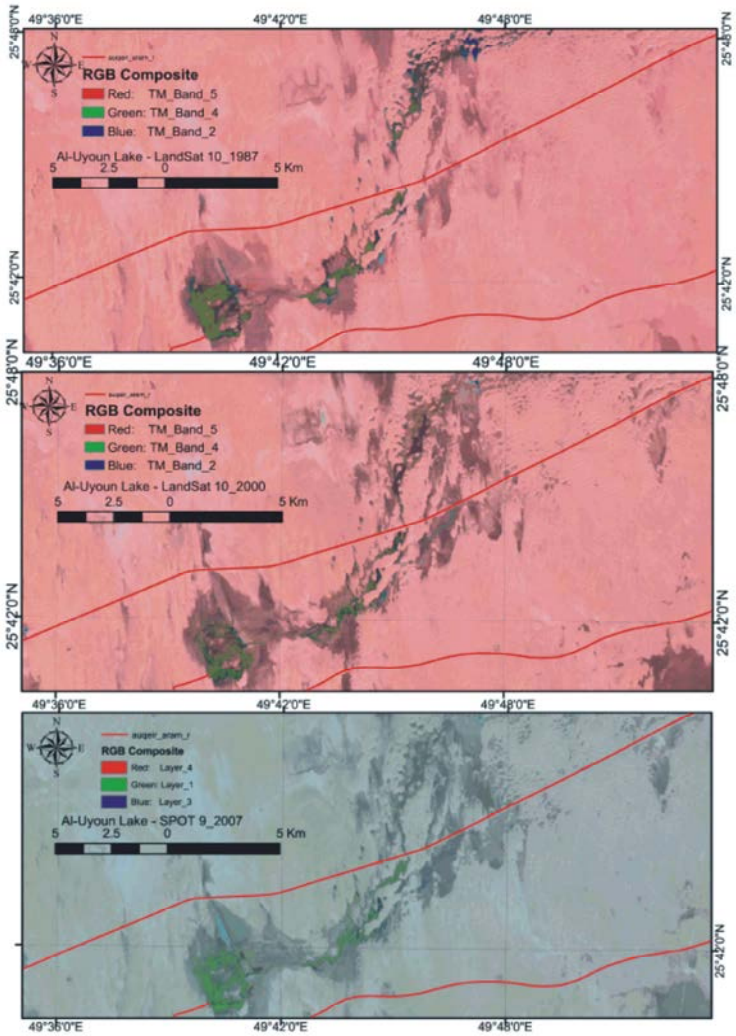


Fig. 4: The processed landsat-5 TM Imageries (in Years of 1987 &2000) and SPOT (in Year 2007) for Al Uyoun area.

Table 1: Descriptive statistics of the different grain size parameters for the analyzed sabkha soil samples, Al Uyoun lake area, Al Hassa, KSA.

| Variable | Mz (Φ) | $\sigma_I$ (Φ) | $SK_D$ | $K_G$ |
|---|---|---|---|---|
| Range | 0.6:2.58 | 0.6:1.94 | -0.29:0.29 | 0.79:1.78 |
| Average | 1.37 | 1.07 | 0.07 | 1.07 |
| Standard Deviation | 0.33 | 0.23 | 0.12 | 0.13 |

**Sedimentological Results:** Grain size distribution analysis, determination of carbonate, sand and mud contents and organic matter content for the ninety five samples collected from of Al Uyoun area have been done. In the following is the discussion of the result of each analysis.

**Grain Size Analysis:** The main purpose of grain size analysis is to get an idea about the size spectrum of the sabkha samples under investigation. It is also gives information on the energy of the medium of deposition, where coarse particles are usually transported in higher energy environment, whereas low energy environment transports finer sediments. It is also worthy to add that the statistical parameters of grain size and their mutual relationships provide us with information on agents of transportation as well as the environment of deposition.

Grain size statistical parameters form the basis of many schemes for classifying sedimentary environments. The size distribution of coarse clastic sediments reflects the fluidity (viscosity) factor of the depositing medium and the energy factor of the environment (site) of deposition [17]. Grain size parameters include graphic mean size (Mz), inclusive graphic standard deviation (σI), inclusive graphic skewness (SKI) and graphic kurtosis (KG) were calculated. The estimation of the statistical grain-size parameters was accomplished using the mathematic formulas of Folk and Ward [18]. Table (1) shows the descriptive statistics of the different grain size parameters for the analyzed sabkha soil samples. ArcGIS software has been used to produce spatial distribution maps for these parameters. These maps will generally be used to estimate the relation between grain size distribution and the Sedimentological and geomorphologic features of the area.

The average value of Mz is 1.37 Φ (medium sand). The Mz values indicated that most of the samples of sabkha deposits were composed of medium sand. Figure (5a) represents the spatial distribution of Mz for the analyzed samples in the study area. This map indicated that the fineness, generally, was getting towards the northwest of the area of study. This distribution is related to the sources of sediments and the geomorphologic features including the drainage system and the digital elevation model of the study area (Fig., 3). Only two samples (No's 33 and 78) were fine sands and were attributed to fine sediments coming from the mouth of the main Drain (D1) and the floods of the main lake of Al Uyoun. The southeastern part of the area was characterized by coarse sand and due to its low topography and quite near location to the sand dunes area, these coarse sands were accumulated. However the coarse sands of Samples Nos. 13 and 14 to the north of Aramco road are attributed to the exiting of the sand dunes at these locations.

The average value of sorting (σI) was 1.07 Φ (poorly sorted). The samples of moderately to moderately well sorted were located to the southeast of the study area and around the mouth of Drain 1, (Fig.,5b). From this map, it is clear that Al Uyoun area was generally characterized by poorly sorted sediments which could be attributed to the different sources of sediments (sabkha, alluvial deposits and aeolian sediments and dust storms) and the effect of geomorphology. This interpretation was in good matching with the direction of the prevailing wind in Al Hassa Oasis from north to the south and as well from the constructed digital elevation model map area (Fig. 3).

The average value of SKI was 0.07 Φ, which was near symmetrical. The obtained data showed that most sediment of all the studied sabkha deposits were near symmetrical. The southern, the southwestern and the northeastern parts of the area were of fine skewed (positive values of SKI) (Fig., 5c). It is worth to mention that there was a good matching between the map of Mz distribution (Fig., 5a) and the map of SKI (Fig., 5c). For example the patches of the negative skewed around the location of samples 9, 18, 28, 29, 33, 41, 49, 69 and 74, which were located around the wetlands, were of fine particles and was clearly indicated on the map of Mz (Fig. 5a).

The sediment samples in the study area were inclined towards the ''mesokurtic'' (average value of kurtosis is KG 1.07 Φ, ranging between platykurtic (0.79) to very leptokurtic (1.78), (Fig., 5d). The data obtained for KG indicated that the Al Uyoun sabkha sediments were mesokurtic (58.95%), leptokurtic (36.84%) and platykurtic (4.21%). This may also be attributed to the variety of sediment sources and the complexity of surface geomorphology of the area. Platykurtic sediments are mostly associated with the poorly sorted sediments and this was clear if the patches of platykurtic were compared

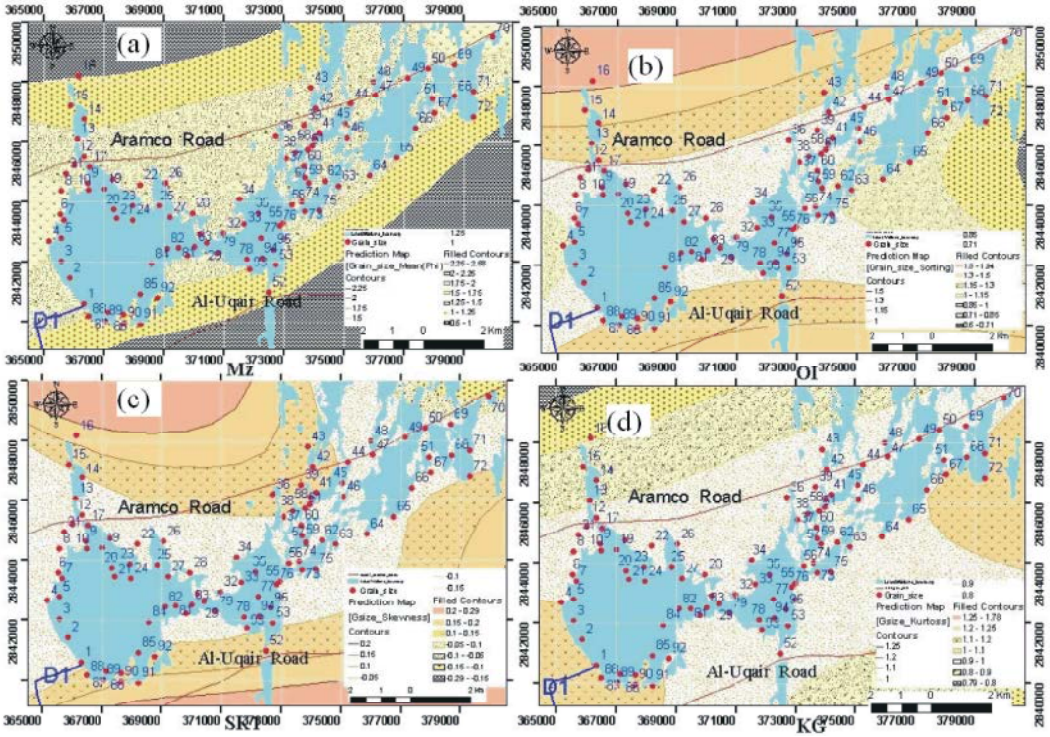


Fig. 5: Distribution of Grain Size Statistical Parameters in the Al Uyoun Area, (a) Mean Grain Size, (b) Sorting, (c) Skewness and (d) Kurtosis.

at the map (Fig., 5d). For example, areas around samples No's 15, 16 and 49, they were poorly sorted as shown in figure (5b).

In general, the grain size statistical analyses indicated that most of the areas are composed of two or more classes of sediments transported and deposited from different sources; which are aeolian sand, sabkhas and drain input and coastal features. The variability in the grain size statistical parameters may be attributed to the complexity of surface morphology as well as the diversity in the type of depositional environment in Al Uyoun area.

**Determination of Carbonate, Sand and Mud Contents:** Figures (6a, b and c) show the spatial distribution of the carbonate, sand and mud respectively. From the grain size analysis and from these maps, it is clear that the Al Uyoun sabkha is in general of sand and sandy silt. Also, it could be noticed clearly that, the mud content is generally increased in the northern and southern parts of the study area and is attributed to the discharged water from the main drain D1 (Fig., 2). While, the carbonate content is increased in the northern western corner of the study area and this is attributed to the dissolution of carbonate rocks from the scattered outcrops existing at some parts of the study area.

**Organic Matter Content:** The organic matter content for these sabkha soil samples was analyzed. The high values of the organic matter content (around sample No. 33) were belonging to samples located quite near to the periphery of the main lake of Al Uyoun, (Fig., 6d) and this could be attributed to the accumulation of the decayed vegetation with depth at these locations. A relative high organic value was existed at the northwestern corner of the study area (Fig. 6d).

**Chemical and Hydrochemical Investigations:** The samples were analyzed for their physical and chemical properties such as pH, EC, TDS and cations ($Na^+$, $Ca^{++}$, $K^+$ and $Mg^{++}$) as well as anions ($Cl^-$, $SO_4^{--}$, $HCO_3^-$ and $NO_3^-$). Table (2) summarizes the statistical analysis of chemical properties of the collected samples of the sabkha soil, surface water and soil water of Al Uyoun area. From this table it could be noticed that, the major cations were in the order $Na^+$, $K^+$, $Ca^{++}$ and $Mg^{++}$, while the major anions were in the order: $Cl^-$, $SO_4^{--}$, $HCO_3^-$ and $NO_3^-$. The carbonate content was so low to be detected as the maximum value of pH was not more than 8.3 which is the threshold of this anion to start to be formed in both soil and water [19].

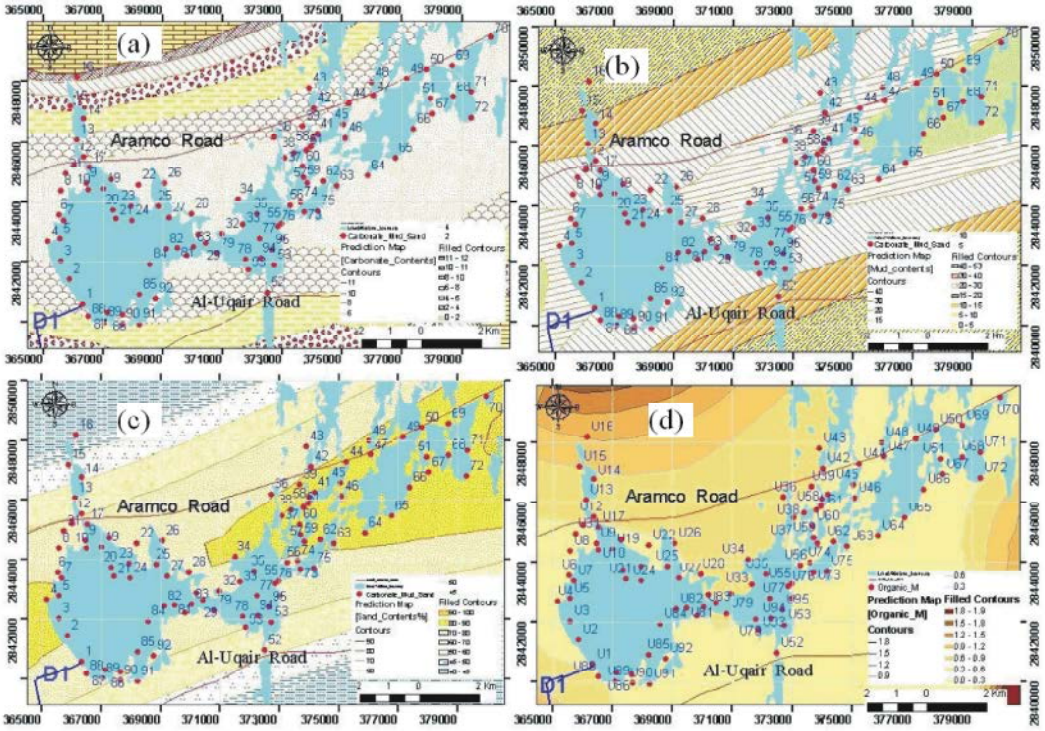


Fig. 6: The spatial distribution of a) carbonate, b) sand, c) mud and d) organic matter contents in the inland sabkha samples of Al Uyoun area, Al Hassa, KSA.

Table 2: Statistical analysis for the parameters of chemical properties (pH, EC, TDS) and for the major cations and anions for Al Uyoun sabkha soil, surface water and for pore water samples

| | | | | | Analysis | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Major Cations (ppm) | | | | Major Anions (ppm) | | | |
| Type | Values | pH | Ec (ds/m) | TDS (ppm) | $Na^+$ | $Ca^{++}$ | $K^+$ | $Mg^{++}$ | $Cl^-$ | $SO_4^-$ | $HCO_3^-$ | $NO_3^-$ |
| Soil samples | Minimum | 6.41 | 11.45 | 9160 | 788.2 | 570.7 | 125.0 | 384.0 | 2339.4 | 2082.1 | 46.7 | 3.5 |
| | Maximum | 8 | 103.5 | 82800 | 16650.8 | 3524.8 | 4401.5 | 3601.2 | 21474.3 | 20740.3 | 264.4 | 121.0 |
| | Mean | 7.301 | 56.038 | 44830.1 | 7267.6 | 1443.2 | 1632.1 | 1648.7 | 11603.6 | 11173.4 | 113.1 | 17.1 |
| | SD* | 0.389 | 24.109 | 19287.1 | 4153.8 | 581.3 | 915.1 | 571.1 | 5003.4 | 4891.2 | 43.8 | 21.8 |
| Water samples | Minimum | 6.85 | 7.49 | 5992 | 532.9 | 275.0 | 100.3 | 231.7 | 1349.7 | 1313.8 | 155.6 | 1.3 |
| | Maximum | 8.94 | 99.58 | 79664 | 17284.0 | 2539.3 | 6023.7 | 2424.5 | 20813.1 | 19595.5 | 1648.8 | 99.0 |
| | Mean | 7.959 | 41.13 | 32903.6 | 5087.2 | 1241.2 | 1444.7 | 1098.5 | 8446.6 | 7948.3 | 391.0 | 9.3 |
| | SD* | 0.4351 | 28.474 | 22779.5 | 5039.8 | 480.5 | 1653.8 | 607.2 | 5944.7 | 5633.1 | 291.1 | 17.7 |

*Standard Deviation

The pH was measured for all sediment samples and water samples. Figures (7a and b) show the spatial distribution map of pH values for soils and water, respectively along the Al Uyoun area. Obviously all the samples (soils and water) showed a slightly alkaline character with very narrow pH ranges. The soil samples having pH values varying between 6.41 and 8, while the water samples having pH values 6.85 and 8.94. From the pH map of soil, it could be noticed that pH values were increasing northward and the samples located to the northeast corner had the maximum pH values. Also, the area around the mouth of main drain (D1) was characterized by high pH values. The pH values for water samples (7b) had the similar distribution pattern of that of soils shown in figure (7a).

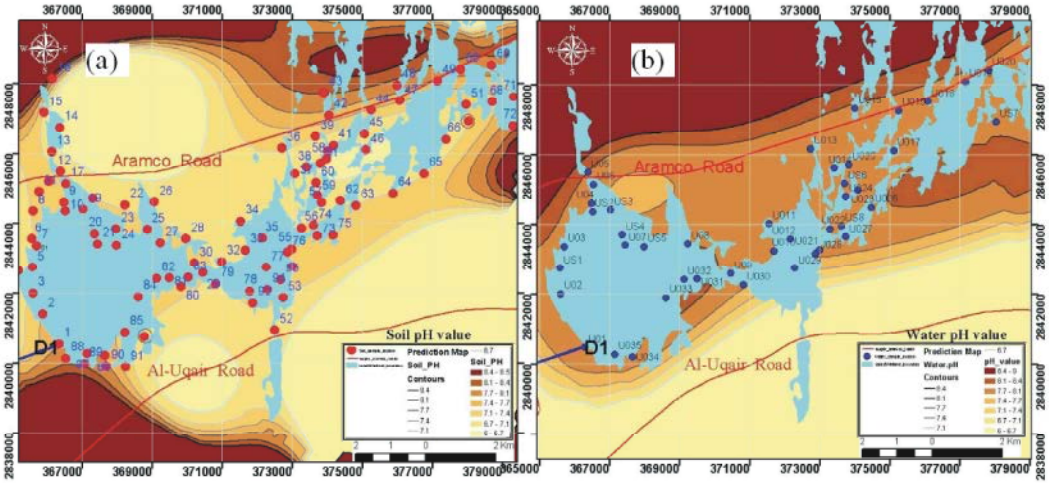


Fig. 7: Distribution map of the pH of the soil (a) and water (b) of Al Uyoun inland sabkha, Al Hassa area, KSA.

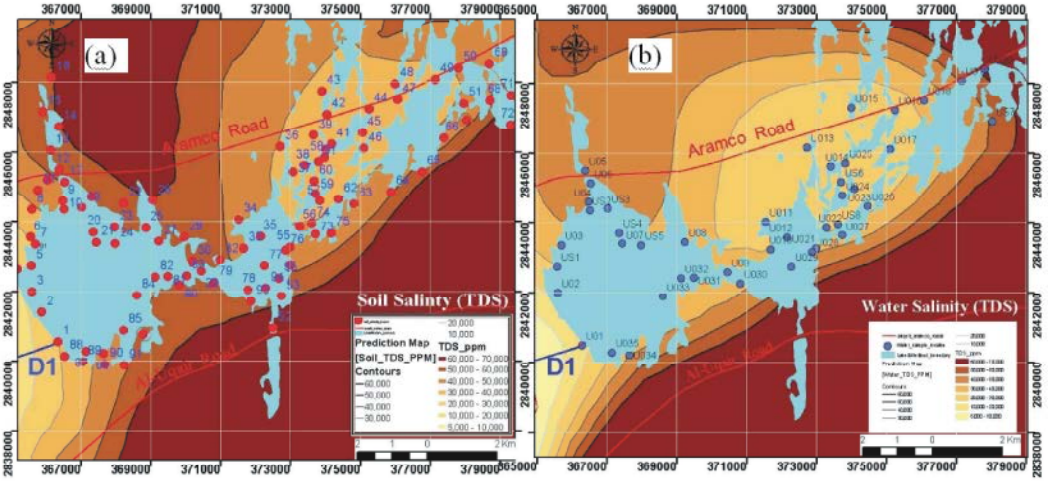


Fig. 8: Spatial Distribution map of the total salinity a) for the soil and b) for the surface water and soil water of Al Uyoun area, Al Hassa area, KSA.

For the studied sabkha sediments, the total salinity ranged between 9,160 and 82,800 ppm, with mean value of 44830 ppm. The soil and water salinity were increasing towards the southeast and northeast direction (Fig. 8, a and b). This could be attributed to the effect of leaching process in the down-gradient direction.

The area surrounding the wet parts of Al Uyoun was characterized by low salinity content and this was due to flushing effect of drain two (D2). The higher salinity could be attributed to the influence of the intermittent charge and for the high evaporation rate. From the spatial distribution of the salinity of the sabkha soils, it was clear that salt content had a significant effect on the sabkha grade and had its effect on sabkha spectral signature on Landsat-5 TM & SPOT imageries used in this study (Fig. 4).

The total salinity of surface water and pore water samples ranged from 5992 to 79,664 ppm with mean value of 32,903 ppm (Fig., 8b). The relatively low values of total salinity were belonging to the surface water samples from the main lake of Al Uyoun (Fig., 8b). This relatively low salinity encouraged to retreat Al Uyoun lake water and to reuse it in agricultural purposes, which will lead to minimize the sabkha extension, to mitigate its impact on the nearby farms of Al Hassa Oasis and to mitigate aquifer recharge with high saline water and to optimize the water use of this surface water body in this arid environment. The increase of salinity of this lake is due to its closed nature, shallow depth of water, restricted condition and minor connection with continuous fresh water source.

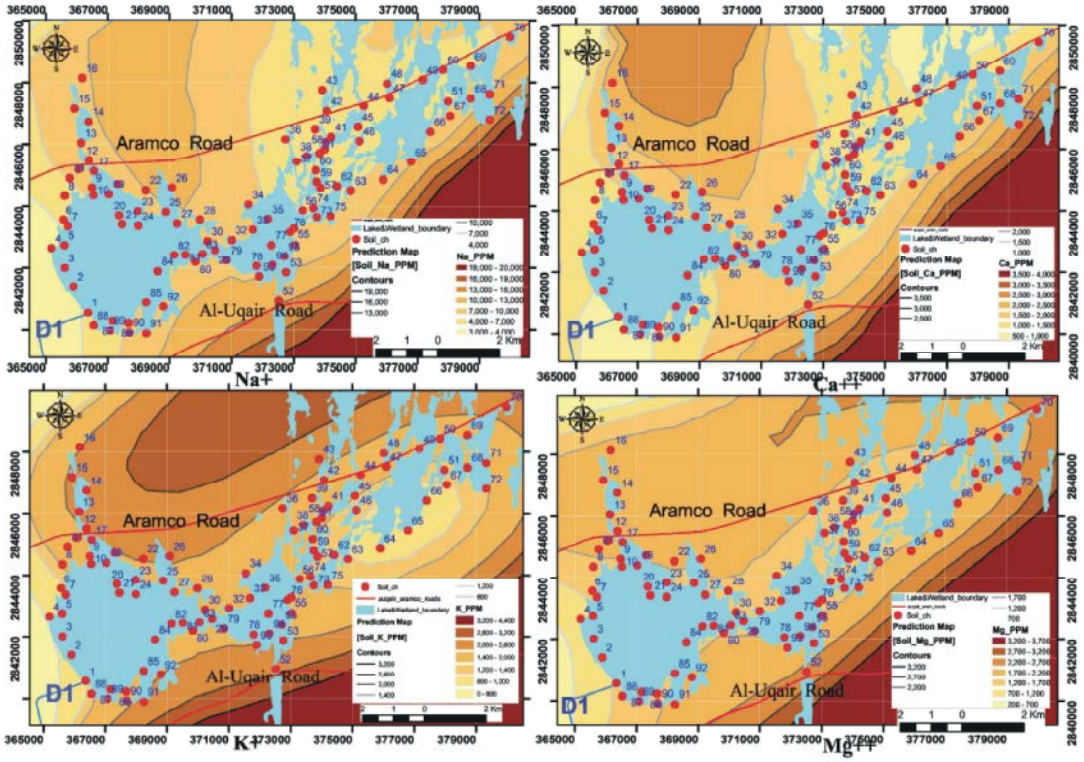


Fig. 9(a): Distribution maps of the major cations concentration for the soil of Al Uyoun area, Al Hassa, KSA.

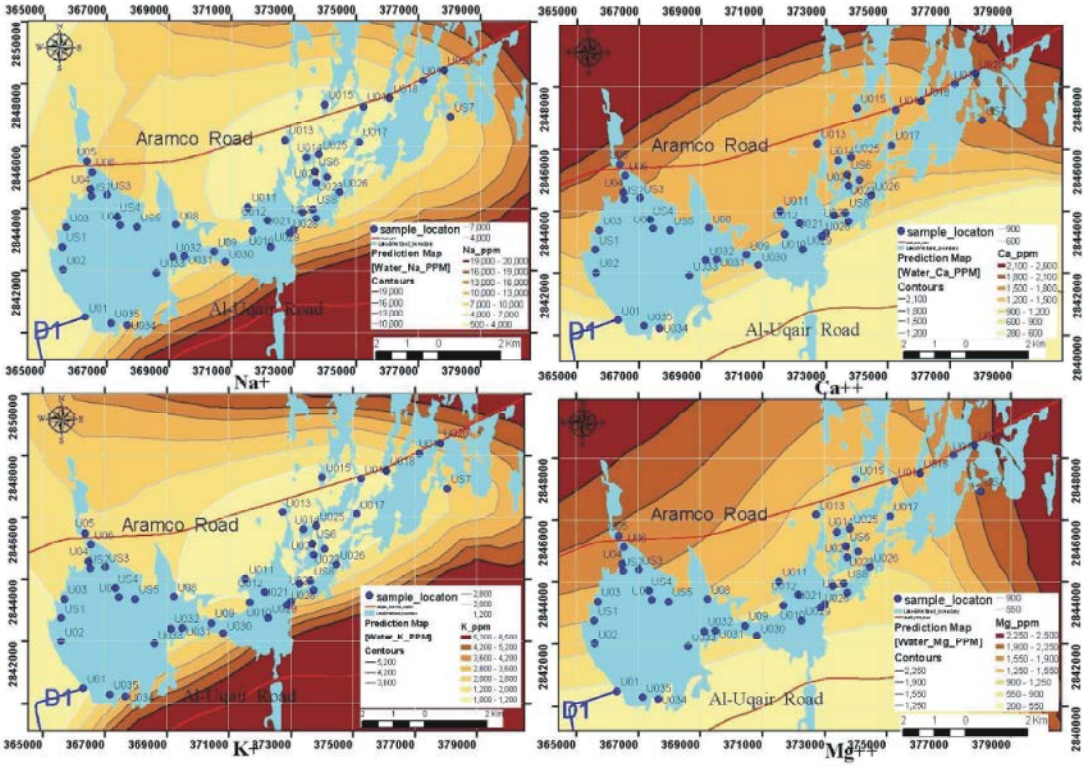


Fig. 9(b): Distribution maps of the major cations concentration for the surface water and soil water of Al Uyoun area, Al Hassa, KSA.

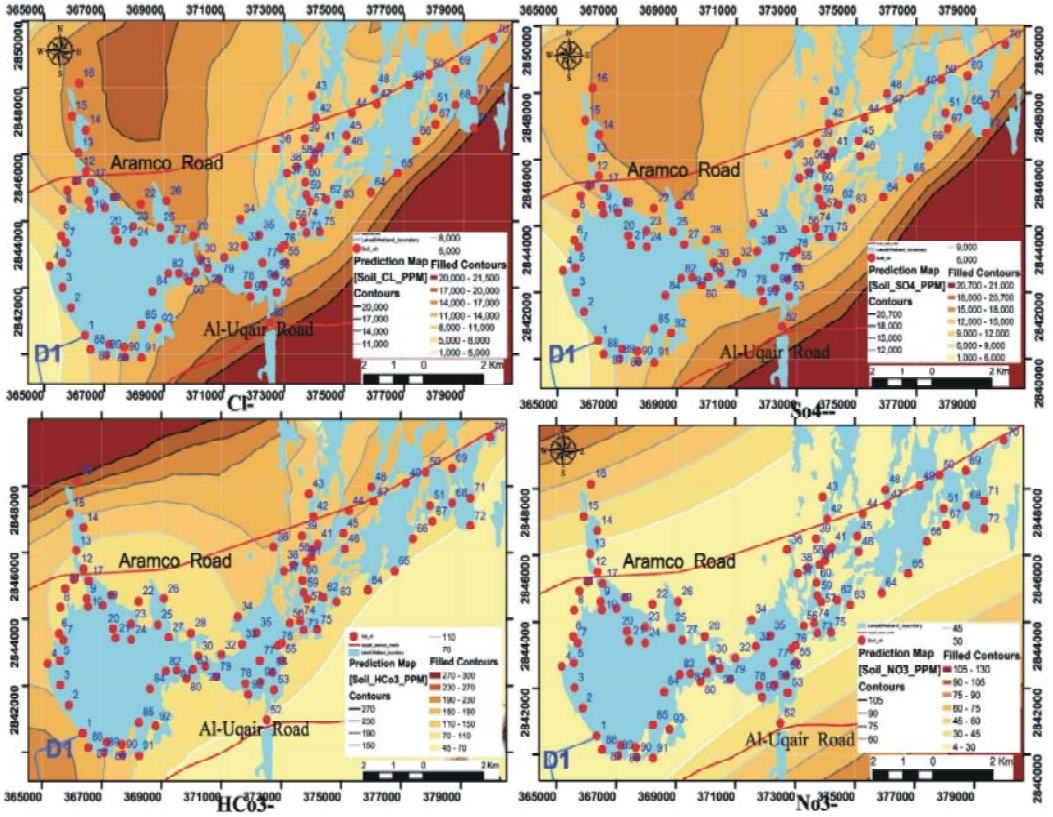


Fig. 10(a): Distribution maps of the major anions concentration for the soil of Al Uyoun area, Al Hassa, KSA.

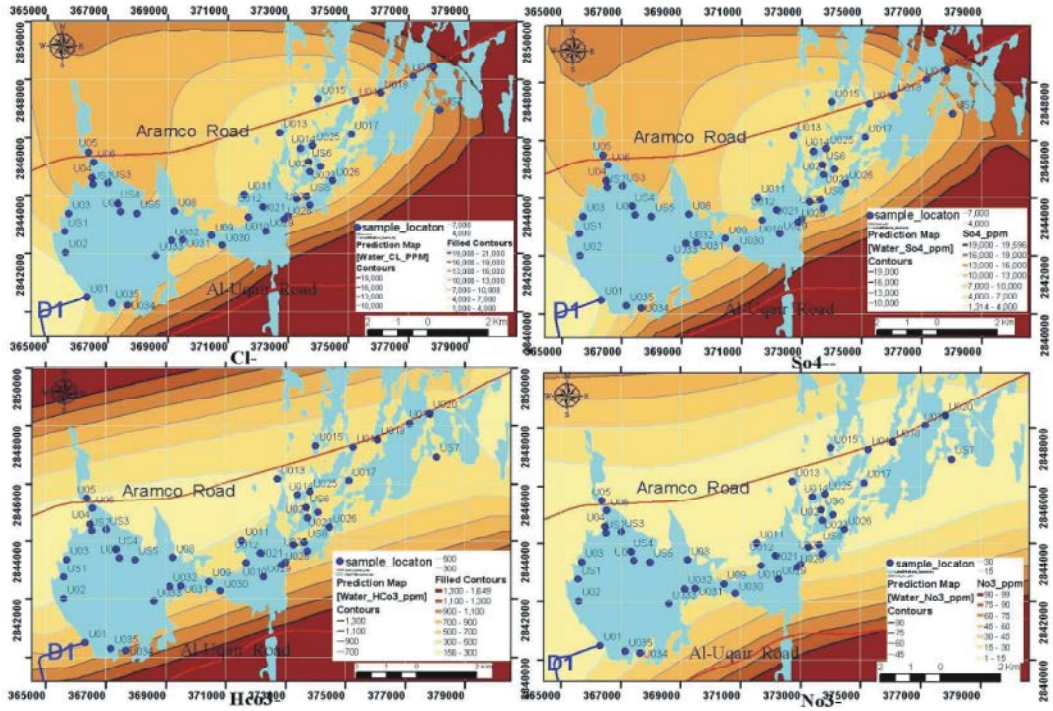


Fig. 10(b): Distribution maps of the major anions concentration for the surface water and soil water of Al Uyoun area, Al Hassa, KSA.

The soil water salinity at the margins of Al Uyoun Lake ranged from 26,312 ppm to 71,400 (Fig. 8b). The salt content of soil water for the collected samples depends on the distance from the main water body of Al Uyoun Lake, i.e. the nearest to the lake, the less of salt content. The soil water under this sabkha was more saline than the normal sea water.

It is worthy to mention that the contour pattern of the constructed spatial distribution maps for the major cations of soil samples (Fig.,9a) were similar to that of TDS (Fig., 8a). The same feature was also noticed for the major cations of water samples (Figs., 8b and 9b). However, in case of anions the contour pattern for chloride and sulphate had the similar pattern of TDS (Figs., 8a and b), while for both bicarbonate and nitrate had a different pattern (Figs., 10a and b). The bicarbonate in this sabkha is thought to be derived partly from the outcrops of Neogene carbonate ridges originated under marine conditions. It is worthy to mention that the bicarbonate ions distribution either in soil or in water (Figs., 10a and b) was in a good match with carbonate content distribution of soil sabkha samples (Fig., 6a).

The major hydrodynamic process operating in this inland sabkha is upward migration of the brines by capillary movement precipitating salts. The presence of salts at the surface was due to the rate of evaporation at the sabkha surface at these sites which exceeded the total input of water to the sabkha, so that high concentration of TDS in the water are reached [20]. The variation in the salinity was relatively influenced by the following factors; evaporation, the lithologic characteristics of the soils, as well as transportation, solubility of salts and the rate of discharge of the surface water from the agricultural drains to Al Uyoun Lake.

The rate of evaporation in the inland sabkhas is supposedly higher than that in the coastal ones due to the more arid conditions. Consequently, the ground-water table plays a substantial role in the development of inland sabkhas, which are usually less developed than coastal sabkha flats and are predominantly tectonically and/or topographically controlled [21]. The sediments of these sabkhas consisted predominantly of gypsum (desert roses), quartz and calcite, with halite always existing at the crust [22]. The crustal part is the product of a combination of geological processes like desiccation, weathering and, above all, cementation of the salts precipitated through evaporation of highly saline groundwater. Khedr [23] suggested terms such a growth or development of sabkhas through this latter process as "sabkhaization".

Further, these results shed light on the maturity status of the inland Sabkha of Al Uyoun area. Thus the observed higher TDS in both soil and water confirmed the slightly developed to developed nature of sabkha as per the classification of Bahafzallah *et al*. [24].

## CONCLUSIONS

The integration between modern techniques of remote sensing and GIS with conventional Sedimentological and chemical investigations has led to a better understanding of the environment of Al Uyoun Evaporation Lake through the current study. The Landsat-5 TM and SPOT imageries indicated that there was a general shrinkage in both sabkha and wetland areas with time. Different sabkha grades were recognized showing various degrees of salt content as it is indicated from the TDS spatial distribution of Al Uyoun area. This study concluded that the surface water of Al Uyoun Lake is characterized by a relatively low salinity. The retreatment of this water could help in reusing it for agricultural purposes which will lead to minimize the sabkha extension, to mitigate its impact on the nearby farms of Al Hassa Oasis, to mitigate aquifer recharge with high saline water and to optimize the water use in such arid environment.

Chemical results are very important to be taken in consideration by Saudi Aramco, as the different sabkha grades have their various corrosion levels that may affect the pipelines crossing this sabkha area. Sabkha dynamics information and chemical results gained from the current study may be utilized to optimize the pipelines maintenance and future cost effective pipelines route planning. The evaporation condition prevailing in the present study and the absence of continuous recharge from the main drainage (D1) have led to highly concentrated saline lagoon water. The major hydrodynamic process is possibly the upward migration of subsurface brines from groundwater by capillary action due to evaporation and precipitating salt on the surface.

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