Distribution and Significances of the Major Oxides in Recent Coastal Sabkha Sediments of the Al-Dafna Plateau, Northeast Tobruk, Libya

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Abstract

Twenty sabkha samples were chemically analyzed by XRF technique for determination of their major oxides concentrations. Six cores penetrated both the intertidal and supratidal flat zones developed in six wadis mouths in the coastal stretch of the Al-Dafna plateau, northeast Tobruk city. The significance distribution and concentration of the major oxides are discussed and interpreted. Elements in the raw material of the study area reflect important evidence of geochemical weathering processes that affecting parent rocks as well as conditions of sedimentation, and rate of deposition. Correlation coefficients have been used to illustrate the abundance and distribution of these elements.

The distribution of major oxides are follows Si₂O > CaO > LOI > Al₂O₃ > SO₃ > MgO > Na₂O > K₂O. The vertical distribution of major elements is mainly controlled by the abundance and proportions of the clastics, carbonates and evaporite minerals. It was found that silica present in the form of detrital, subrounded to rounded silt- to sand-sized quartz grains, while the content of Al₂O₃ is associated with terrigenous argillaceous materials. On the other hand, the presence of Fe₂O₃ is related to the abundance of clastic materials in sabkha deposits. It was found that K₂O and Na₂O concentrations increase toward the sabkha surfaces.

Keywords:
Al-Dafna plateau,
Major oxides,
Intertidal sabkha,
Supratidal sabkha,
Wadis mouths.

1 Introduction

Sabkhas are widespread geomorphological features in the coastal landforms of the Mediterranean Sea of Libya. Wadis sabkhas always subjected to flash floods during the rainy season in the main Wadis and/or recharge from tidal flow. A tidal pool partially filled with seawater during high tide flood seasonally and daily thus intertidal and supratidal sabkhas are developed. A marine sabkha is a near coastal salt dominated by marine-derived brines and processes; a continental sabkha is an inland salt flat dominated by continental brines and processes (Prudencio et al., 2007). The study area is characterized by the presence of many geomorphological coastal forms and bays. The coastline extends from the Wadi El-Shawash estuary in the west to the Ramla well in the east at the western border of the Arab Republic of Egypt. The sand dunes, the Sabkhas and the pockets are abundant in this area (Al-Haram, 1997). An attempt has been made herein to study the geochemical features regarding both abundance and vertical distribution of major elements in the raw sabkha samples of intertidal and supratidal zones. The chemical composition of the sabkha deposits provide important information in order to define and understand the basic processes involved in major elements transport during and after the deposition of the sabkha deposits. Also the chemical analysis is used to find out the general trend of the chemical composition as well as support the trend of mineralogical composition through the vertical profiles. Geologists may use geochemical information to improve understanding of geological processes, including the origin, formation, and composition of rocks and sediments (Rollinson et al., 2014). X-ray
fluorescence is a non-destructive technique for analysis of elemental composition. XRF is a well-established analytical technique used for estimating the chemical composition of rocks and sediments both in the field and the laboratory (Potts et al., 1997).

The present work aims to determine the Significances and distribution of the major elements in the studied sabkha deposits.

2 Techniques of the study

Two field trips were conducted to the study area along the coastal stretch of the Al-Dafna plateau (150 km from northeast Tobruk city, Libya) where temperature ranging from 25°C to 40°C in the winter and summer 2018, respectively. Twenty samples of sabkha deposits were chemically analysed for determination of their major elements. X-Ray Fluorescence (Model ARL9900-X-Ray) at Al Arish Cement Company (ACC) was used for major chemical oxides determination in the raw sabkha samples. X-ray fluorescence is a nondestructive technique for analysis of element composition. Flame photometer instrument PFP7 was used for assurance of XRF results. The samples are irradiated by a strong X-ray beam which leads to emission of X-rays. XRF is a well-established analytical technique used for estimating the chemical composition of rocks and sediments both in the field and the laboratory (Potts et al., 1997; Ramsey et al., 1995). Wavelengths make it possible to detect which elements are present in the samples. The intensity of these characteristic X-rays give information about the abundance of different elements. A computer was utilized for gathering information. Wet analytical analysis was applied for chemical assurance of SiO₂, Al₂O₃, Fe₂O₃, CaO and MgO.

Percentages of silica (SiO₂), alumina (Al₂O₃), ferric oxide (Fe₂O₃), lime (CaO), magnesium oxide (MgO), sulfur trioxide (SO₃), sodium oxide (Na₂O), potassium oxide (K₂O) chloride content (Cl⁻) and loss on ignition (LOI) were determined.

2.1 Study area

The study area occupies the northeastern coast of Libya (Figure 1); where sabkhas are common in the coastal area of Al Dafna plateau which extends from the mouth of Wadi Umm El-Shawash in the west (east of Tobruk City), to Bir Al Ramla Weep in the eastern border of Libya with Egypt for about 130 km long. The area lies between Longitude 24° 00' to 25° 08' E and Latitude between 31° 45' to 32° 21' N (Figure 1). The study area has a Mediterranean climate where arid to semiarid conditions are dominant. The average temperature is ranging from 25 to 40°C in summer months and from 10 to 20°C during winter. The rainy season is limited and often concentrated in few showers from October to March. While December and January months are the wet. Al Dafna plateau in the north eastern side of Libya is characterized by different sabkhas developed at Wadis mouths, Wadi Al-Sawai sabkha, Wadi Rizk sabkha, Umm Rukbah sabkha, Wadi Alain sabkha, Alaqila sabkha, and Wadi Umm El-Shawash sabkha. Supratidal and intertidal sabkhas are developed in the Wadis mouths in the coastal area of Al Dafna plateau where desiccation in tidal flat areas causes precipitation of gypsum and halite.

Figure 1: Satellite image showing the location of the studied coastal sabkhas in Al-Dafna plateau. (\*)
3 Results

Major elements distribution

Data of the major oxides concentration is studied sabkhas are summarized below:

SiO$_2$

The silica content in the analyzed sabkha samples ranges from 43.8 to 50.83 % with an average of 46.51 % in intertidal zone (Table 1) (Figure 2), and varies between 37.31% and 49.11% with average of 44.82% in supratidal zone (Table 2) (Figure 3).

Al$_2$O$_3$

The content of Al$_2$O$_3$ in the analyzed sabkha of the intertidal zone varies between 7.01 % and 11.3 % with an average of 8.9 % (Table 1 and Figure 2), whereas in supratidal zone the content ranges from 4.54 % to 10.1 % with an average of 7.61% (Table 2 and Figure 3).

Fe$_2$O$_3$

The content of iron in the analyzed sabkhas varies between 1.21 and 3.83 % with an average of 2.47 % in intertidal sabkha (Table 1) and ranges from 0.19 % to 3.15 % with average of 1.90 % in supratidal sabkha (Table 2).

CaO

Calcium content fluctuated between 8.72 and 23.04 % with an average of 15.19 % in intertidal area (Table 1) and ranges from 10.84 % to 39.33 % with an average of 20.50 % in supratidal area (Table 2).

MgO

Magnesium oxide content in the examined sabkhas ranges from 0.089% to 5.24 % with an average of 3.31 % in intertidal zone (Table 1) and varies between 1.92 % and 5.68 % with average of 3.56 % in supratidal zone (Table 2).

SO$_3$

Contents of SO$_3$ in the studied sabkhas vary between 0.08 and 7.33 % with an average of 4.22 % in intertidal area (Table 1) and ranges from 1.02 % to 14.16 % with average of 5.63 % in supratidal area (Table 2).

Na$_2$O

The content of Na$_2$O in the studied intertidal sabkha varies between 0.15 % and 5.72 % with an average of 1.61 % (Table 1 and Figure 2), whereas the content of Na$_2$O in the studied supratidal sabkha ranges from zero to 5.29 % with an average 1.61 % (Table 2 and Figure 3).

K$_2$O

Trends of K$_2$O in the analyzed sabkhas show values ranging from 1.11 to 1.72 % with an average of 1.36 % in intertidal sabkha (Table 1) and varying between 0.68 % and 2.8 % with average of 1.36 % in supratidal sabkha (Table 2).

Cl$^-$

Chlorine concentration in the studied intertidal sabkha varies between 0.897 % and 6.39 % with an average value of 2.25 % (Table 1 and Figure 2), whereas the content in the supratidal sabkha ranges from 0.52 % to 5.36 % and its average value is 2.72 % (Table 2 and Figure 3).
Table 1. Major oxides concentration in the studied intertidal sabkha sediment

| S.no | Core No. | Depth cm | Sabkha         | Location | Major Oxides | Organic matter % | Carbonate % | Mud % |
|------|----------|----------|----------------|----------|--------------|------------------|-------------|-------|
|      |          |          |                |          | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | SO₃ | Na₂O | K₂O | Cl⁻ | LOI |              |              |        |       |
| 1    | 1        | 0-5      | Wadi Al-Sawani | Intertidal | 47.91 | 8.48 | 2.23 | 14.5 | 2.5 | 1.05 | 2.89 | 1.29 | 3.61 | 15.54 | 21 | 39 | 53 |
| 3    | 15-20    |          |                |          | 50.83 | 7.73 | 1.71 | 12.59 | 2.09 | 1.08 | 0.15 | 1.16 | 0.897 | 21.763 | 0.1 | 40 | 38 |
| 6    | 0-4      |          | Wadi Rizk      |          | 46.51 | 7.01 | 1.21 | 23.04 | 2.48 | 0.089 | 0.408 | 1.11 | 2.27 | 15.87 | 6 | 40 | 54 |
| 7    | 5-14     |          |                |          | 46.16 | 7.09 | 1.45 | 22.38 | 2.63 | 1.62 | 1.303 | 1.13 | 2.96 | 13.277 | 8 | 42 | 55 |
| 9    | 25-28    |          |                |          | 46.76 | 7.84 | 1.91 | 18.21 | 2.59 | 3.911 | 1.66 | 1.19 | 2.94 | 12.989 | 7.6 | 42 | 49 |
| 10   | 0-5      | Omm Rukbah |                |          | 46.16 | 7.09 | 1.45 | 22.38 | 2.63 | 1.62 | 1.303 | 1.13 | 2.96 | 13.277 | 8 | 42 | 55 |
| 11   | 0-5      | Wadi Al Ain |                |          | 48.31 | 9.44 | 2.77 | 8.72 | 3.67 | 4.95 | 5.24 | 1.39 | 5.09 | 10.42 | 6 | 28 | 55 |
| 16   | 0-5      |          |                |          | 43.8 | 9.19 | 2.81 | 16.46 | 3.42 | 12.6 | 5.72 | 1.31 | 4.41 | 0.28 | 15 | 45 | 54 |
| 17   | 20-30    |          |                |          | 45.03 | 11.3 | 3.83 | 12.25 | 3.83 | 2.76 | 4.73 | 1.72 | 6.39 | 8.16 | 11.4 | 48 | 49 |
| 18   | 0-5      | Alaqila   |                |          | 44.52 | 10.3 | 3.39 | 12.99 | 5.24 | 5.56 | 4.5 | 1.61 | 6.26 | 5.63 | 14 | 58 | 41 |
| 20   | 20-25    |          |                |          | 44.87 | 9.99 | 3.06 | 14.42 | 4.24 | 7.33 | 3.67 | 1.53 | 4.86 | 6.03 | 13 | 39 | 60 |
|      |          |          |                |          | Average | 46.51 | 8.9 | 2.47 | 15.2 | 2.32 | 4.23 | 3.04 | 1.36 | 4.03 | 10.94 | 10 | 42.18 | 51.18 |
|      |          |          |                |          | Min | 43.8 | 7.01 | 1.21 | 8.72 | 2.09 | 0.09 | 0.15 | 1.11 | 0.90 | 0.28 | 0.1 | 28 | 38 |
|      |          |          |                |          | Max | 50.83 | 11.3 | 3.83 | 23.04 | 5.24 | 12.6 | 5.72 | 1.72 | 6.39 | 21.76 | 21 | 58 | 60 |

Table 2. Major oxides concentration in the studied supratidal sabkha sediment

| S.no | Core No. | Depth cm | Sabkha         | Location | Major Oxides | Organic matter % | Carbonate % | Mud % |
|------|----------|----------|----------------|----------|--------------|------------------|-------------|-------|
|      |          |          |                |          | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | SO₃ | Na₂O | K₂O | Cl⁻ | LOI |              |              |        |       |
| 4    | 2        | 0-5      | Wadi Rizk      | Supratidal | 43.09 | 4.54 | 0.19 | 39.33 | 1.92 | 2.81 | 0 | 0.68 | 0.52 | 6.92 | 2.64 | 64 | 27 |
| 5    | 2        | 5-15     |                |          | 43.54 | 5.05 | 0.36 | 37.01 | 2.28 | 0.63 | 0 | 0.81 | 0.75 | 9.57 | 4.5 | 83 | 16 |
| 6    | 3        | 0-5      | Omm Rukbah     |          | 46.58 | 9.94 | 2.95 | 14.57 | 3.49 | 1.02 | 2.43 | 1.57 | 3.09 | 14.36 | 9.9 | 45 | 54 |
| 8    | 3        | 20-25    |                |          | 46.77 | 10.1 | 3.15 | 10.84 | 5.11 | 1.34 | 5.29 | 1.51 | 5.36 | 10.53 | 16.3 | 37 | 60 |
| 9    | 4        | 0-5      | Wadi Al Ain    |          | 49.11 | 9.46 | 2.66 | 12.61 | 2.66 | 0.15 | 0.336 | 1.51 | 0.919 | 20.585 | 7.2 | 43 | 55 |
| 14   | 5        | 0-5      | Alaqila        |          | 44.83 | 8.15 | 1.95 | 15.93 | 4.35 | 14.16 | 2.01 | 1.19 | 3.42 | 4.01 | 6.4 | 50 | 49 |
| 17   | 30-35    |          |                |          | 44.65 | 9.13 | 2.71 | 16.04 | 5.68 | 8.85 | 1.68 | 1.36 | 2.79 | 7.11 | 9.2 | 46 | 53 |
| 18   | 6        | 0-10     | Wadi Omm       |          | 47.46 | 6.11 | 1.07 | 19.39 | 2.09 | 7.31 | 0.46 | 0.88 | 2.243 | 12.987 | 4.2 | 51 | 36 |
| 21   | 30-35    |          | El-Shawesh     |          | 37.31 | 5.97 | 2.1 | 18.8 | 4.53 | 14.4 | 2.31 | 2.8 | 3.89 | 10.2 | 9.9 | 48 | 10 |
|      |          |          |                |          | Average | 44.82 | 7.61 | 1.90 | 20.5 | 3.57 | 5.63 | 1.61 | 1.37 | 2.55 | 10.69 | 7.8 | 52 | 40 |
|      |          |          |                |          | Min | 37.31 | 4.54 | 0.19 | 10.84 | 1.92 | 0.15 | 0.00 | 0.68 | 0.52 | 4.01 | 2.64 | 37 | 10 |
|      |          |          |                |          | Max | 49.11 | 10.1 | 3.15 | 39.33 | 5.68 | 14.40 | 5.29 | 2.80 | 5.36 | 20.58 | 16.3 | 83 | 60 |
Table 3. Correlation coefficients of major oxides for the studied intertidal sabkha sediments.

|       | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | SO₃ | Na₂O | K₂O | Cl⁻ | LOI | Organic matter % | Carbonate % | Mud % |
|-------|------|-------|-------|-----|-----|-----|------|-----|-----|-----|------------------|-------------|-------|
| SiO₂  | 1.0  |       |       |     |     |     |      |     |     |     |                  |             |       |
| Al₂O₃ | 0.663| 0.971 |       |     |     |     |      |     |     |     |                  |             |       |
| Fe₂O₃ | 0.284| 1.0   |       |     |     |     |      |     |     |     |                  |             |       |
| CaO   | 0.821| 0.834 | 1.0   |     |     |     |      |     |     |     |                  |             |       |
| MgO   | -0.477| 1.0 |      |     |     |     |      |     |     |     |                  |             |       |
| SO₃   | 0.526| 0.536 | 1.0   |     |     |     |      |     |     |     |                  |             |       |
| Na₂O  | 0.728| 0.730 | 1.0   |     |     |     |      |     |     |     |                  |             |       |
| K₂O   | 0.355| 0.717 | 1.0   |     |     |     |      |     |     |     |                  |             |       |
| Cl⁻   | 0.885| 0.868 | 1.0   |     |     |     |      |     |     |     |                  |             |       |
| LOI   | 0.384| 0.663 | -0.705| 1.0 |     |     |      |     |     |     |                  |             |       |

Table 4. Correlation coefficients of major oxides for the studied supratidal sabkha sediments.

|       | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | SO₃ | Na₂O | K₂O | Cl⁻ | LOI | Organic matter % | Carbonate % | Mud % |
|-------|------|-------|-------|-----|-----|-----|------|-----|-----|-----|------------------|-------------|-------|
| SiO₂  | 1.0  |       |       |     |     |     |      |     |     |     |                  |             |       |
| Al₂O₃ | 0.656| 0.902 |       |     |     |     |      |     |     |     |                  |             |       |
| Fe₂O₃ | 0.144| 0.914 | 0.901 |     |     |     |      |     |     |     |                  |             |       |
| CaO   | 0.914| 0.947 | 1.0   |     |     |     |      |     |     |     |                  |             |       |
| MgO   | -0.357| 1.0 |      |     |     |     |      |     |     |     |                  |             |       |
| SO₃   | 0.869| 0.851 | 1.0   |     |     |     |      |     |     |     |                  |             |       |
| Na₂O  | 0.728| 0.730 | 1.0   |     |     |     |      |     |     |     |                  |             |       |
| K₂O   | 0.355| 0.717 | 1.0   |     |     |     |      |     |     |     |                  |             |       |
| Cl⁻   | 0.885| 0.868 | 1.0   |     |     |     |      |     |     |     |                  |             |       |
| LOI   | 0.384| 0.663 | -0.705| 1.0 |     |     |      |     |     |     |                  |             |       |
Figure 4. Diagrams showing the correlations of some major elements with each other in the studied intertidal sabkha

Figure 5. Diagrams showing the correlations of some major elements with each other in the studied supratidal sabkhas
4 Discussion

Significances distributions of the major oxides in both types of studied sabkhas are summarized in the following:

**Silicon dioxide**, also known as silica, silicic acid or silicic acid anhydride is an oxide of silicon with the chemical formula SiO₂. Calculations of correlation coefficients of major element concentrations in the studied sabkha samples are shown in (Table 3) and illustrated in (Figure 4). In intertidal sabkha, SiO₂ is positively correlated with LOI (r = 0.873) and negatively correlated with Fe₂O₃, MgO, SO₃, Na₂O, K₂O, Cl⁻, organic matter and carbonate contents (r = -0.503, -0.623, -0.602, -0.567, -0.656, -0.564 and -0.561, respectively). In supratidal sabkha, high positive correlation exists between silica, Al₂O₃, LOI and mud content (r = 0.56, 0.502 and 0.78, respectively (Table 4). In contrast, SiO₂ is strongly negatively correlated with SO₃ and K₂O (r = -0.576 and -0.516, respectively) (Figure 5). Silica in the studied sabkha occurs in the form of detrital, rounded to subrounded sand to silt-sized quartz grains.

**Aluminum** is an important component of particulate matter derived from continents (Taylor & McLennan, 1985), so it is used to trace the abundance of the terrestrial components. Alumina in intertidal zone has a strong positive correlation with Fe₂O₃, MgO, Na₂O, K₂O and Cl⁻ (r = 0.995, 0.821, 0.814, 0.975, and 0.902, respectively, Table 3 and Figure 4). In addition Al₂O₃ has negative correlation with CaO and LOI (r = -0.71 and -0.656, respectively). In supratidal zone, Al₂O₃ has strong positive correlations with Fe₂O₃, MgO, Na₂O, K₂O, Cl⁻, organic matter and mud contents (r = 0.937, 0.592, 0.627, 0.534, 0.726 and 0.897, respectively, Table 4). Alumina has strong negative correlation with CaO and carbonate content (r = -0.862 and 0.897, respectively) (Figure 5). This trend indicates its association with terrigenous argillaceous materials as evidenced by (Murray et al., 1992). Aluminum is mainly hosted in clay minerals and occasionally in detrital feldspars (Albarede, 2003). Aluminum solubility in hydrous fluids is low, except at very high temperature and high pH (Hem, 1970; Albarede, 2003).

In intertidal zone, **Ferric oxide** has a strong positive correlations with MgO, SO₃, Na₂O, K₂O and Cl⁻ (r = 0.834, 0.526, 0.848, 0.964 and 0.914, respectively) (Table 3 and Figure 4) and a negative correlation with LOI (r = -0.7). In supratidal zone, Fe₂O₃ has a strong positive correlation with MgO, Na₂O, K₂O, Cl⁻, organic matter and mud content (r = 0.730, 0.721, 0.571, 0.683, 0.838 and 0.72, respectively Table 4). In contrast, Fe₂O₃ strongly negatively correlated with CaO and carbonate content (r = -0.920 and -0.865) (Figure 5).

The presence of iron is related to the increase of clastic materials in sabkha deposits (Mohamed, 1993).

The vertical distribution of CaO and MgO and the correlation matrix show that MgO correlates negatively with CaO (r = -0.477) (Tables 3 and 4 and Figures 4 and 5) in the studied sabkhas.

The antipathetic behavior between Ca and Mg is attributed to the dolomitization process (Brand and Veizer, 1980). The XRF Data analyses show that dolomite in the studied sabkha is very rare so that MgO contents are very low. In the intertidal zone, MgO has a positive correlation with SO₃, Na₂O, K₂O, Cl⁻ and organic matter (r = 0.452, 0.752, 0.546, 0.791, and 0.766, respectively, Table 3 and Figure 3) and negative correlation with LOI. In the supratidal zone, MgO has positive correlations with SO₃, Na₂O, K₂O, Cl⁻ and organic matter (r = 0.452, 0.752, 0.546, 0.791 and 0.766, respectively, Table 4 and Figure 5).

**Sulfur trioxide** is the chemical compound with the formula SO₃, with a relatively narrow liquid range. In the gaseous form, this species is a significant pollutant, being the primary agent in acid rain (Loerting et al., 2000). It is prepared on an industrial scale as a precursor to sulfuric acid. In perfectly dry apparatus, sulfur trioxide vapor is invisible, and the liquid is transparent. However, it fumes profusely even in a relatively dry atmosphere (it has been used as a smoke agent) due to formation of a sulfuric acid mist. This vapor has no odor but is extremely corrosive (Lerner, 2011). Sulfur trioxide has a strong positive correlation with Na₂O and Cl⁻ (r = 0.730 and 0.469, respectively, Table 1.3 and Figure 4) in intertidal area, whereas in supratidal area, SO₃ has a strong positive correlation with K₂O (r = 0.433, Table 4 and Figure 5) and negative correlation with LOI (r = 0.549).

**Sodium oxide** content shows upward increase through the different cores taken in the studied sabkhas where its maximum values occur at the surface. Na₂O represents the most abundant cations in the sea water and should be a good indicator of salinity (Moore and Billings, 1971). If Na₂O content is less than 0.05%, this indicates contribution of freshwater, while if it is higher than 0.3%, this denotes marine influence (Ernest, 1970). In the intertidal sabkha, Na₂O has positive correlations with K₂O, Cl⁻ and organic matter content (r = 0.717, 0.868 and 0.537, respectively) (Table 3 and Figure 4), whereas it has a negative correlation with LOI (r = -0.851). While the supratidal sabkha, Na₂O has positive correlations with K₂O, Cl⁻, organic matter and mud contents (r = 0.468, 0.943, 0.940 and 0.453, respectively) and a negative correlation with carbonate content (r = -0.651) (Table 4 and Figure 5). The slightly high content of the Na₂O in the studied sabkha is mainly due to the presence of the halite at the sabkha surface.

**Potassium oxide** in intertidal sabkha, has a strong positive correlation with Cl⁻ (r = 0.904, Table 3) and a negative correlation with LOI (r=-0.595) (Figure 4). In supratidal sabkha K₂O exhibits strong positive correlations with Cl⁻ and organic matter content (r =
0.562 and 0.574, respectively, Table 4) (Figure 5) and a negative correlation with carbonate content ($r = -0.506$). Like Na$_2$O, potassium oxide values increase upward in the studied sabkha.

In intertidal sabkha, chloride has a positive correlation with organic matter content ($r = 0.521$) and a negative correlation with LOI ($r = -0.774$) (Table 3 and Figure 4). In supratidal carbonate, Cl$^-$ has a strong positive correlation with organic matter content ($r = 0.853$) and a negative correlation with carbonate content ($r = -0.672$) (Table 4 and Figure 5).

5 Conclusion

The studied coastal sabkha were subdivided into two types; intertidal and supratidal sabkhas. Geochemical analyses in the recorded sabkha deposits reveal enrichment of SiO$_2$, Al$_2$O$_3$, and Fe$_2$O$_3$ due to abundance of clastic materials that are dominated by silt- to sand-sized quartz grains. CaO and MgO oxides are recorded with limited distribution due to the presence of chemically precipitated some calcite and dolomite in the analyzed sabkha deposits reflecting the weak supplied sea water to the studied sabkha.

Conflict of interest: The authors declare that there are no conflicts of interest.

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