Abstract

The two main particle size components of the dust samples were subjected to mineralogical analysis to identify the mineral constituents and determine their frequency percentage in each textural class; the fine sand (particle size between 0.125 and 0.063 mm) and Mud (less than 0.063 mm).

The average percentage of minerals was mapped out for each season i.e. March, June, September and December 2010 showing the high and low mineral concentration in areas in Kuwait covering the mineral concentrations of Calcite, Carbonate, clay minerals, dolomite, feldspars, and quartz.

Methodology

The two main particle-size components of the dust samples were subjected to mineralogical analysis, namely:

1. Very fine sand (particle size between 0.125 mm and 0.063 mm);
2. Mud (less than 0.063 mm).

The mineralogical analysis of dust particles was performed to identify the mineral constituents and to determine their frequency percentage in each textural class. The whole components of the dust samples were gently powdered and analyzed using XRD and a Philips PW-1830 Powder Diffractometer, and data were semi-quantitatively analyzed using X’Pert II software. Furthermore, to observe seasonal variations, the following four months’ worth of samples was analyzed:

1. March 2010;
2. June 2010;
3. September 2010;
4. December 2010.

There were 47 site locations for the selected four months.
The mineralogy of dust fallout in Kuwait contains quartz, calcite, carbonates, dolomites, feldspars, and a small percentage of other minerals. Quartz and carbonates form the significant percentage of dust fallout mineralogy. The percentage of carbonates, in general, was highest during winter (October–April). Calcite, as a major constituent of carbonates in Kuwait, was higher in Liyah and coastal areas and extending toward the northwest. The Dibdibah Formation contains calcretes and dolcretes as a major source of carbonate dust.

Fig. 4.1 Average percentages of calcite, December 2010
The mineralogy of dust fallout in Kuwait constitutes carbonates as a main component. Quartz and carbonates form the major percentage of dust fallout mineralogy. The percentage rate of carbonates, in general, was highest in winter and springtime (October–April). Carbonates in Kuwait were greater in Liyah and in the coastal area that extends toward the northwest. The Dibdibah Formation contains calcretes and dolcretes as a major source of carbonate dust.

| Areas with high mineral concentration | Areas with low mineral concentration |
|--------------------------------------|-------------------------------------|
| Liyah                                | Roudhatain                          |
| Huwaymilyah                           | Dibdibah                            |
| Abdullah                              | Ahmadi                              |
| Salmi                                 | Qurain                              |
| Mutla                                 | Khur Fawaris                         |
The mineralogy of dust fallout in Kuwait contains a small percentage of clay minerals. This percentage, in general, was highest during wintertime (October–April). Clay minerals, as a minor constituent in Kuwait, were more present in Salmi, Dibdibah, and Liyah, as well as in the drainage systems, including “wadis” and “playas,” which are the primary local sources of dust in Kuwait.

| Areas with high mineral concentration | Areas with low mineral concentration |
|--------------------------------------|-------------------------------------|
| Salmi                                | Roudhatain                          |
| Dibdibah                             | Bubiyan Island                      |
| Liyah                                | Kabd                               |
| Ahmadi                               | Qurain                             |
| Ubayriq                              | Wafra Farms                        |
Dust fallout in Kuwait contains appreciable amounts of dolomite. Quartz and carbonates form the major percentage of dust fallout mineralogy. The percentage of carbonates, in general, was highest during winter (October–April). Calcite, as a significant constituent of carbonates in Kuwait, was higher in Liyah and coastal areas and extends toward the northwest. The Dibdibah Formation contains calcretes and dolcretes as a major source of carbonate dust.

| Areas with high mineral concentration | Areas with low mineral concentration |
|---------------------------------------|-------------------------------------|
| Parts of Bubiyan Island                | Liyah                               |
| Jal Al Zur                             | Dibdibah                            |
| Shuaiba                                | Kabd                                |
| Ubayriq                                | Qurain                              |
| Khiran                                 | Um Al Madafi’                        |

**Fig. 4.4** Average percentages of dolomite, December 2010
Dust in Kuwait contains considerable amounts of feldspar minerals (alkali and plagioclase feldspars). The percentage of feldspar, in general, was highest in winter and spring (October–April). Feldspar content was as high as 44% in the Shuaiba area. Feldspars act as a primary component of rock-forming minerals and are classified as “soft” (6 on the Moho Hardness scale). Therefore, they disintegrate quickly and are transported in the form of dust for long distances, passing the Arabian Gulf from Iran toward Kuwait. Higher percentages were noted in Liyah and the coastal area and extend toward the northwest.
In December, fallen dust had lower quartz percentages than in summertime. The northeastern coastal areas (Bubiyan, Um Niqa) and southwestern border of Kuwait had the highest percentages (up to 61.8%). These percentages in these areas were thanks to the wind direction during these months. The southern coastal areas and major dunes corridor had the lowest percentage (as low as 32%). The higher percentages of quartz indicate high aeolian activity in the region.

Areas with high mineral concentration

- Parts of Bubiyan Island
- Roudhatain
- Dibdibah
- Kabd
- Wafra Farms

Areas with low mineral concentration

- Salmi
- Um Rimam
- Mutla
- Shuaiba
- Um Eish
Fallen dust in Kuwait contains high percentages of carbonates and, more specifically, calcite. Quartz and carbonates form the large percentage of dust fallout mineralogy. The percentage rate of carbonates is usually highest in winter and springtime (October-April). Calcite, as a major constituent of carbonates in Kuwait, is higher in dust as a component in areas such as Salmi, Huwaymilyah, and Jahra due to the wind direction and speed in these months. The Dibdibah Formation contains calcretes and dolcretes as a major source of carbonate dust. Furthermore, the higher percentages of calcites and carbonates indicate lower aeolian activity in the area.
Fallen dust in Kuwait contains high percentages of carbonates (up to 58%). Carbonates, as a major component of dust fallout mineralogy, are good indicators of low aeolian activity in the area during winter and springtime (October–April). Carbonates include dolomite and calcite. There were high percentages of carbonates within dust in Kuwait in areas such as Salmi, Huwaymilyah, and Atraf due to the wind directions and speed in these months. The Dibdibah Formation contains calcretes and dolcretes as a major source of carbonate dust.

**Fig. 4.8** Average percentages of carbonate, March 2010

| Areas with high mineral concentration | Areas with low mineral concentration |
|--------------------------------------|-------------------------------------|
| Salmi                                | Um Al Madafi’                       |
| Huwaymilyah                          | Dibdibah                            |
| Atraf                                | Kabd                                |
| Um Niqa                              | Wafra Farms                         |
| Shuaiba                              | Liyah                               |
High percentages of clay during March 2010 were restricted to major wadis such as Wadi Al-Batin, the Sabkha region, and the northeastern coastal areas in Kuwait, reaching up to 5.1%. Clay was higher also in densely vegetated areas, such as Al-Mutla, a protected habitat in northern Kuwait Bay, as clay mineral is lighter in weight, making it difficult to be captured by vegetation, as quartz and carbonates are. On the other hand, open desert areas in southwestern areas had the lowest percentages.

| Areas with high mineral concentration | Areas with low mineral concentration |
|--------------------------------------|--------------------------------------|
| Huwaymilyah                           | Salmi                                |
| Ubayriq                               | Roudhatain                           |
| Ratqah                                | Kabd                                 |
| Um Niqa                               | Qurain                               |
| Khiran                                | Wafra Farms                          |
Fallen dust in Kuwait contains a considerable percentage of dolomite (up to 15%). Higher percentages of dolomite indicate lower aeolian activity in the area. The Dibdibah Formation contains calcrites and dolcretes as a major source of dolomite dust. During March, carbonates, including dolomite, were lowest in the five major areas indicated on the map. Dolomite, as a major constituent of carbonates in Kuwait, was higher in dust in areas such as Salmi, Huwaymilyah, and Bubiyan Island due to the wind directions and speed.
Alkali and plagioclase feldspar minerals within fallen dust were present in considerable percentages (up to 20.3%) during March. Feldspars are soft (6 on the Moho Hardness scale) and are a major component of rock-forming minerals. Feldspars are easily disintegrated and transported in the form of dust over long distances. In March, higher percentages were noted in areas low in carbonates, such as Liyah, Wafra, and Bubiyan Island.

**Fig. 4.11** Average percentages of feldspars, March 2010

| Areas with high mineral concentration | Areas with low mineral concentration |
|--------------------------------------|-------------------------------------|
| Roudhatain                           | Salmi                                |
| Dibdibah                             | Huwaymilyah                          |
| Bubiyan Island                       | Ubayriq                              |
| Qurain                                | Khur Fawaris                         |
| Liyah                                 | Khiran                               |
Quartz mineral in dust particles was present in high percentages of up to 70% during March, but lower than in summertime. Quartz is highly resistant to disintegration and is classified as hard on the Moho Hardness scale. Quartz is a major component of rock-forming minerals. During March, some areas, such as Liyah, Kabd, and Dibdibah, had higher percentages of quartz, which indicate higher aeolian activities in these regions compared with other regions. Furthermore, during March, fallen dust that contains a higher percentage of quartz indicates a low carbonate content.

Areas with high mineral concentration
- Um Al Madaﬁ’
- Dibdibah
- Kabd
- Wafra Farms
- Liyah

Areas with low mineral concentration
- Salmi
- Huwaymilyah
- Bubiyan Island
- Um Niqa
- Shuaiba
Calcite mineral concentrations in dust fallout during summer differed compared with winter and spring. Higher percentages of calcite were evident in the coastal areas and major wind corridor in Kuwait, reaching up to 40%. Calcite, in higher percentages, covered smaller areas than in winter. This difference is attributed to an increase in aeolian activity during summertime, which causes a decrease of calcite and carbonates in dust fallout content.

**Fig. 4.13** Average percentages of calcite, June 2010

| Areas with high mineral concentration | Areas with low mineral concentration |
|--------------------------------------|-------------------------------------|
| Liyah                                | Um Eish                             |
| Khiran                               | Salmi                               |
| Abdulli                               | Kabd                                |
| Huwaymilyah                           | Khur Fawaris                         |
| Shuaiba                              | Wafra Farms                          |
Carbonate minerals are present in lower percentages of up to 49.7% in July. The low levels of carbonates in dust are good indicators of high aeolian activity in the area during summer. Higher percentages of carbonates within dust in Kuwait were found in areas such as Salmi, Huwaymilyah, and Atraf due to the wind direction and speed within this month, which was predominantly from the northwest. Calcretes and dolcretes within the Dibdibah Formation act as a major source of carbonate dust in the open desert of Kuwait.

**Fig. 4.14** Average percentages of carbonate, June 2010

| Areas with high mineral concentration | Areas with low mineral concentration |
|--------------------------------------|--------------------------------------|
| Parts of Bubiyan Island              | Wafra Farms                          |
| Huwaymilyah                          | Qurain                               |
| Mutla                                | Subiyah                              |
| Shuaiba                              | Burqan                               |
| Khiran                               | Kabd                                 |
There are small percentages of clay minerals within dust fallout in Kuwait. The percentage of clay minerals, in general, is lowest in June (up to 3.7%). Clay minerals, as a minor constituent of dust in Kuwait, are higher in percentage in the coastal area and around wadis, playas, and sabkhas, as these represent major local sources of dust in Kuwait.

| Areas with high mineral concentration | Areas with low mineral concentration |
|--------------------------------------|-------------------------------------|
| Bubiyan Island                        | Ratqa                               |
| Jal Al Zor                            | Um Al Madafi’                       |
| Abdulli                               | Urayfijan                           |
| Atraf                                 | Burqan                              |
| Dibdibah                              | Liyah                               |
There is a considerable percentage of dolomite within fallen dust in Kuwait (up to 13%). Higher percentages of dolomite indicate lower aeolian activity in the area. The Dibdibah Formation contains calcrites and dolcretes as a major source of dolomite dust. During summer, carbonates, including dolomite, are in low percentages within areas affected by active aeolian processes. Dolomite, as a significant constituent of carbonates in Kuwait, was higher in dust in areas such as Salmi, Subiyah, and Atraf due to wind directions and wind speed for these months.
Aeolian activities increase during summer, resulting in an increase in quartz percentages at the expense of other minerals, including alkali and plagioclase feldspar minerals. The dust in Kuwait contains considerable amounts of feldspar minerals. The percentage of feldspars, in general, is lowest during June. Feldspars reach up to 26.7% on Bubiyan Island and preserved areas such as Kabd, Um Rimam, and west Roudhtain. This level is attributed to the effect of native vegetation in controlling quartz but not feldspar minerals.

Fig. 4.17 Average percentages of feldspars, June 2010

| Areas with high mineral concentration | Areas with low mineral concentration |
|--------------------------------------|------------------------------------|
| Parts of Bubiyan Island              | Salmi                               |
| Roudhatain                           | Khur Fawaris                        |
| Kabd                                 | Ubayriq                             |
| Um Rimam                             | Subiyah                             |
| Qurain                               | Dibdibah                            |
The western, northwestern, and southwestern areas of Kuwait had higher percentages of quartz (up to 66.6%). Furthermore, the wind corridor had a higher percentage of quartz among the dust samples. The coastal areas and Bubiyan Island had lower amounts of quartz within the dust samples. Active aeolian processes play a major role in increasing quartz percentages within Kuwait during June. Extensive areas during June and summertime experience higher percentages of quartz.

Fig. 4.18 Average percentages of quartz, June 2010

| Areas with high mineral concentration | Areas with low mineral concentration |
|--------------------------------------|-------------------------------------|
| Salmi                                | Bubiyan Island                      |
| Ratqah                               | Um Rimam                            |
| Dibdibah                             | Shuaiba                             |
| Khur Fawaris                         | Khiran                              |
| Burqan                               | Mutla                               |
In September, calcite, as an essential carbonate mineral, had lower percentages along the northwestern sides of Kuwait and the major wind corridor. Higher percentage rates of up to 18% were evident in coastal areas and protected habitats. The reason for this presence of calcite with carbonates, feldspars, and clay minerals within protected habitats is due to calcite’s light density, meaning it can easily be carried by the wind. Calcite is usually found more in smaller size fractions than quartz, which is predominantly found with medium and fine sand size fractions. Furthermore, the calcite map indicates three areas with higher percentages for all carbonates and clay minerals with dust samples in September, namely Shuaiba, Ritqa, and Liyah.

| Areas with high mineral concentration | Areas with low mineral concentration |
|--------------------------------------|-------------------------------------|
| Bubiyan Island                       | Roudhatain                          |
| Ritqa                                | Ubayriq                             |
| Shuaiba                              | Wafra Farms                         |
| Khiran                               | Kabd                                |
| Abdulli                              | Khur Fawaris                         |
The coastal areas, including Bubiyan Island, had the highest percentages of carbonates (up to 43.3%) of the total weight of dust samples during September. In September, large areas of Kuwait experienced lower percentage rates of carbonates. The wind corridor, western, and northwestern areas had the lowest percentages (as little as 5%) of the total weight of dust samples. The higher percentages of carbonates indicate higher percentages of low size fraction (mainly silt and clay), and higher BET-surface area for dust samples.
The distribution map of clay minerals reveals that the higher percentages are nearly the same as for carbonate minerals during September 2010. The only exception is urban areas, such as Salmiya, which had lower quantities of clay minerals. Areas that experience high aeolian activities, such as the western and northwestern areas of Kuwait, had lower quantities of clay minerals. In September, clay reached up to 11.4% of the total weight of dust samples, mainly in areas such as Bubiyan Island, Um Niqa, and Um Eish.

| Areas with high mineral concentration | Areas with low mineral concentration |
|--------------------------------------|-------------------------------------|
| Bubiyan Island                        | Roudhatain                          |
| Um Eish                              | Ubayiq                              |
| Um Niqa                              | Huwaymilyah                         |
| Khur Fawaris                          | Kabd                               |
| Um Qudayr                            | Salmiya                            |
In September, dolomite, like other carbonates and clay minerals, had lower percentages along the northwestern side of Kuwait and within the major wind corridor. Higher percentage rates of up to 18% were evident in the coastal and preserved areas. The reason for the presence of higher percentages of dolomite with carbonates, feldspars, and clay minerals within preserved areas is due to dolomite’s low density, meaning it can easily be carried by the wind, as it is usually found more within the smaller size fractions when compared with quartz, which is predominantly found with medium and fine sand size fractions.

| Areas with high mineral concentration | Areas with low mineral concentration |
|--------------------------------------|-------------------------------------|
| Bubiyan Island                       | Roudhatain                          |
| Um Eish                              | Ratqah                              |
| Um Niqa                              | Huwaymilyah                         |
| Khur Fawaris                         | Wafra Farms                         |
| Shaiba                               | Liyah                               |

Fig. 4.22 Average percentages of dolomite, September 2010
The feldspar mineral percentages map for September 2010 is nearly opposite to the quartz percentages map for the same month. The feldspar mineral percentages were higher in coastal areas, mainly along the northeastern sides of Kuwait, including Bubiyan Island, Mutla, and around Kuwait Bay. The lowest quantities were along the northwestern and western sides of Kuwait, mainly in Ratqa, Huwaymilyah. The percentages of feldspar reach up to 28.8%. Feldspar minerals disintegrate rapidly, with low hardness on the Moho scale. Therefore, feldspar usually comes from local sources and travels only short distances.
During September, the quartz percentages were higher along the northwestern and western sides of Kuwait, mainly in Ratqa, Huwaymilyah, and Wafra. The lowest quantities were recorded along the coastal areas, Bubiyan Island, Salmiya, and Mutla. The percentages of quartz reached up to 88.4%, indicating that some areas experienced greater aeolian activity, especially those located within active wind corridors in Kuwait.

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