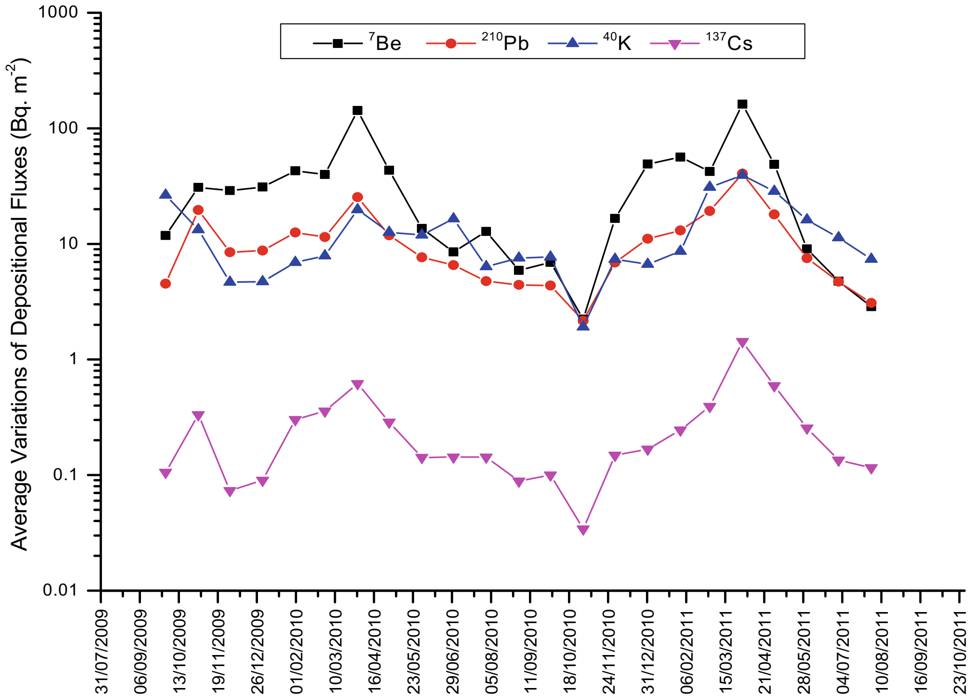


Fig. 6.2 Temporal variations of radionuclide depositional fluxes in Kuwait

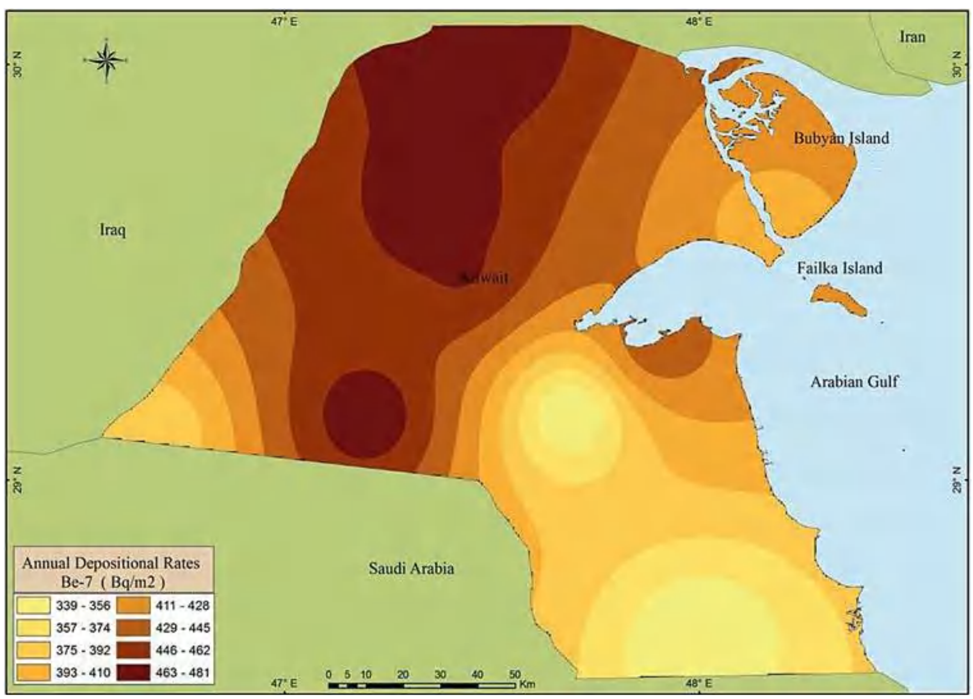


Fig. 6.3 Average deposited rates of ^{7}Be

Monthly Deposited Rates of ^{7}Be

The monthly ^{7}Be deposited rates in Kuwait January 2010–2011 reveal a range from 13.6 to 76.5 Bq m^{-2}, with the maximum in northern areas and the lowest in southern areas. The predominant wind direction for this month was north-westerly (Fig. 6.4).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Abdulli Ratqah Um Eish Raudhatain Huwaymilyah	Salmi Sulaybiyah Wafra Farms KhurFawaris Khiran

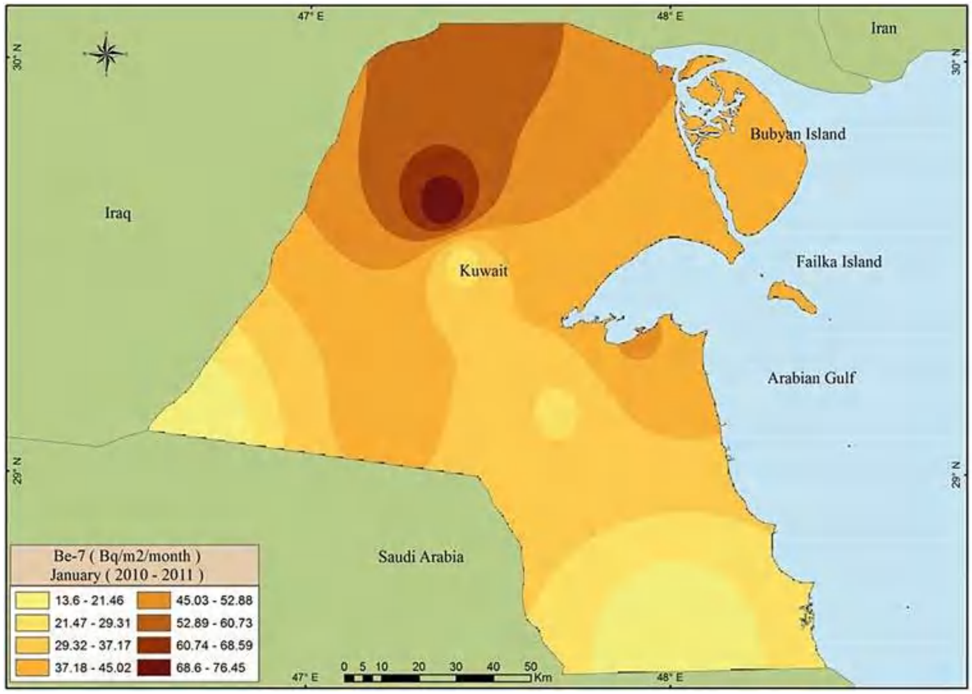


Fig. 6.4 Average deposited rates of ^{7}Be in January (2010–2011)

The monthly rates at which ^{7}Be were deposited in Kuwait in February 2010–2011 which reveal a range from 36.08 to 63.83 Bq m^{-2}, with three maximum spots. This possibly happened because of the effect of dust storms this month. The predominant wind direction for this month was north-westerly (Fig. 6.5).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Bubiyan Bridge	Salmi
Dibdibah	Um Al Madafi’
Wafra Farms	Liyah
KhurFawaris	Shegaya
Subiyah	Um Eish

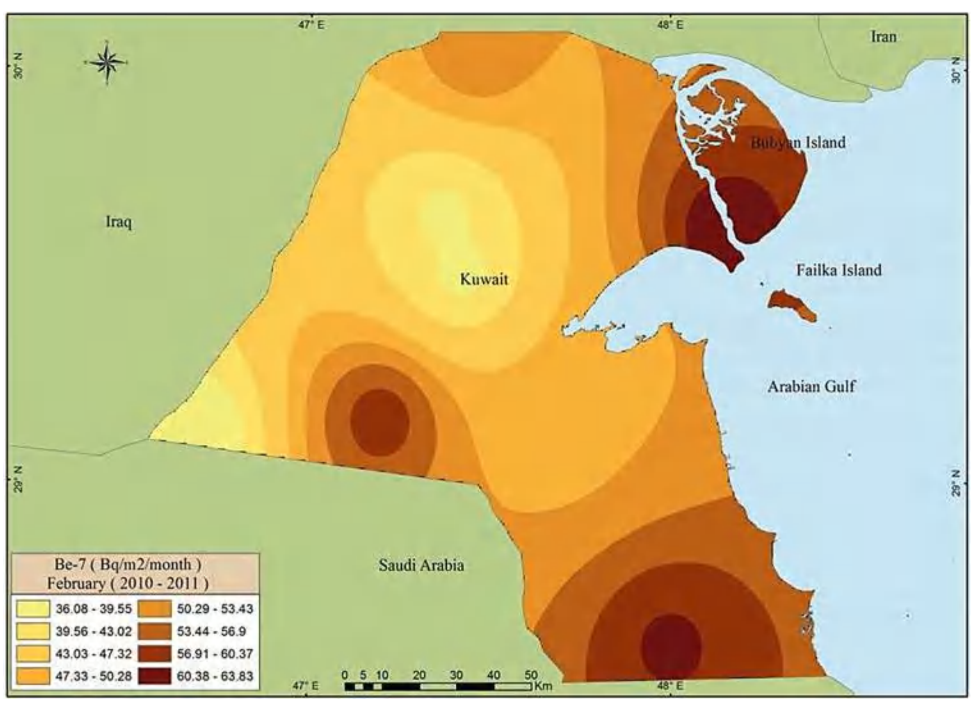


Fig. 6.5 Average deposited rates of ^{7}Be in February (2010–2011)

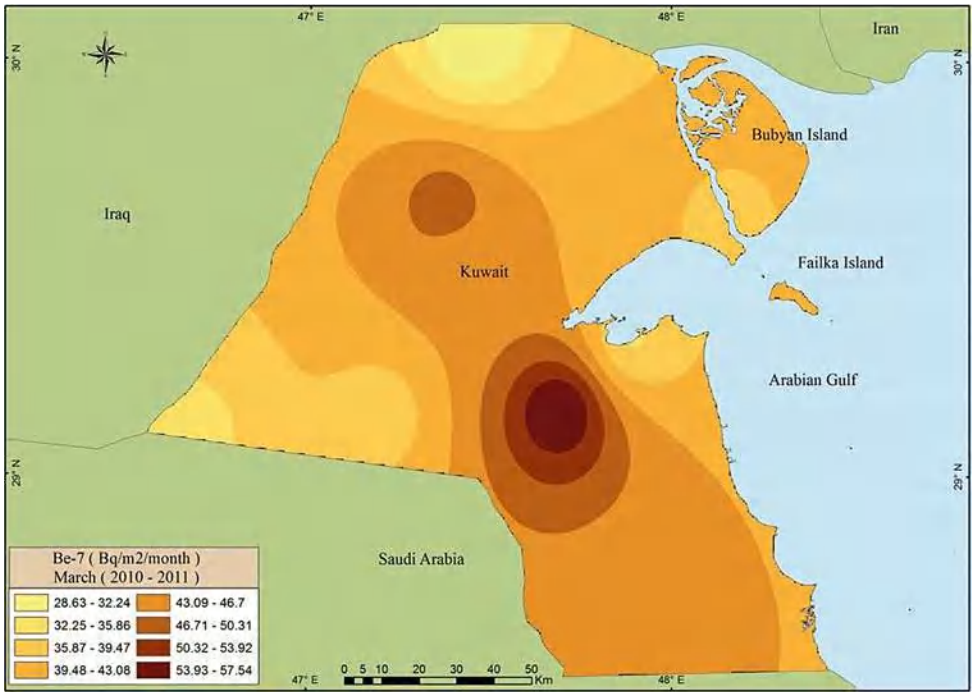


Fig. 6.6 Average deposited rates of ^{7}Be in March (2010–2011)

The monthly ^{7}Be deposited rates in Kuwait during March 2010–2011 reveal a range from 28.63 to 57.54 Bq m^{-2}, with a maximum in the central region with the northern, western wind corridor, and the lowest in the northern area. The predominant wind direction for this month was northwesterly, with high speeds sometimes. However, the occurrence of dust storms was lower in February, as well as precipitation. Nevertheless, the effect of the exotic storm that hit Kuwait in March 2011 led to critical dynamic weather that could probably have decreased the ^{7}Be deposition flux (Fig. 6.6).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Atraf	Abdulli
Um Al Madafi'	Salmi
Liyah	Subiyah
Sulaybiyah	Shegaya
Kabd	Ratqah

The monthly ^{7}Be deposited rates in Kuwait during April 2010–2011 reveal the highest deposited rates, with a range from 106 to 184 Bq m^{-2}, with a maximum in the northern and central areas and the lowest in eastern central areas. The major parameter affecting this high value was the higher precipitation rate in this month (Fig. 6.7).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Abdulli	Salmi
Ratqah	Atraf
Roudhatain	Kabd
Liyah	Sulaybiyah
Salmiya	Wafra Farms

The monthly ^{7}Be deposited rates in Kuwait during May 2010–2011 reveal a range from 27 to 69 Bq m^{-2}, with a maximum in the southern, eastern and northern areas and the lowest in the southern areas. The high values are attributed to the high precipitation rates this month that increased the dust washout (Fig. 6.8).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Salmi	Sulaybiyah
Shegaya	Wafra Farms
Dibdibah	Salmiya
Huwaymilyah	Khiran
Ubayriq	KhurFawaris

The monthly ^{7}Be deposited rates in Kuwait during June 2010–2011 reveal a lower rate than previous months, with a range from 4.23 to 17.32 Bq m^{-2}. The maximum rates were in the northern and western areas, while the lowest were in

Fig. 6.7 Average deposited rates of ^{7}Be in April (2010–2011)

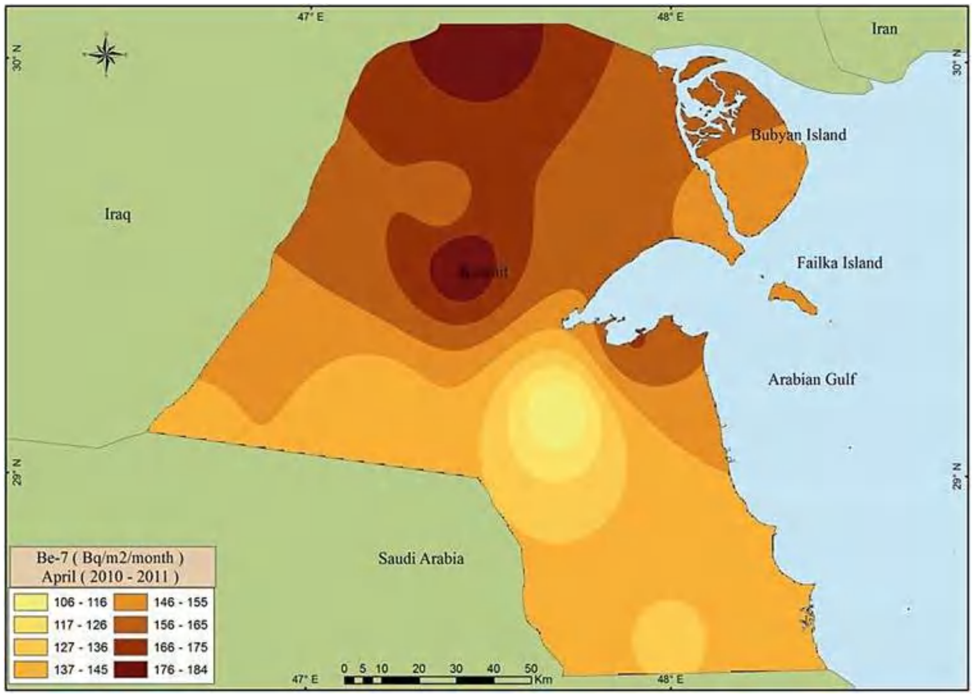
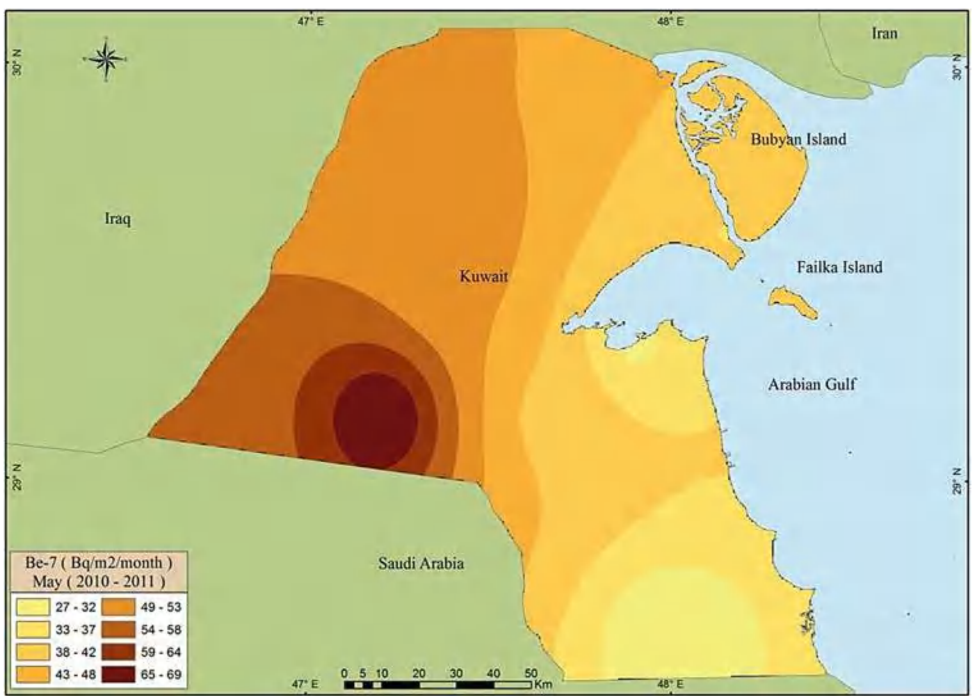


Fig. 6.8 Average deposited rates of ^{7}Be in May (2010–2011)



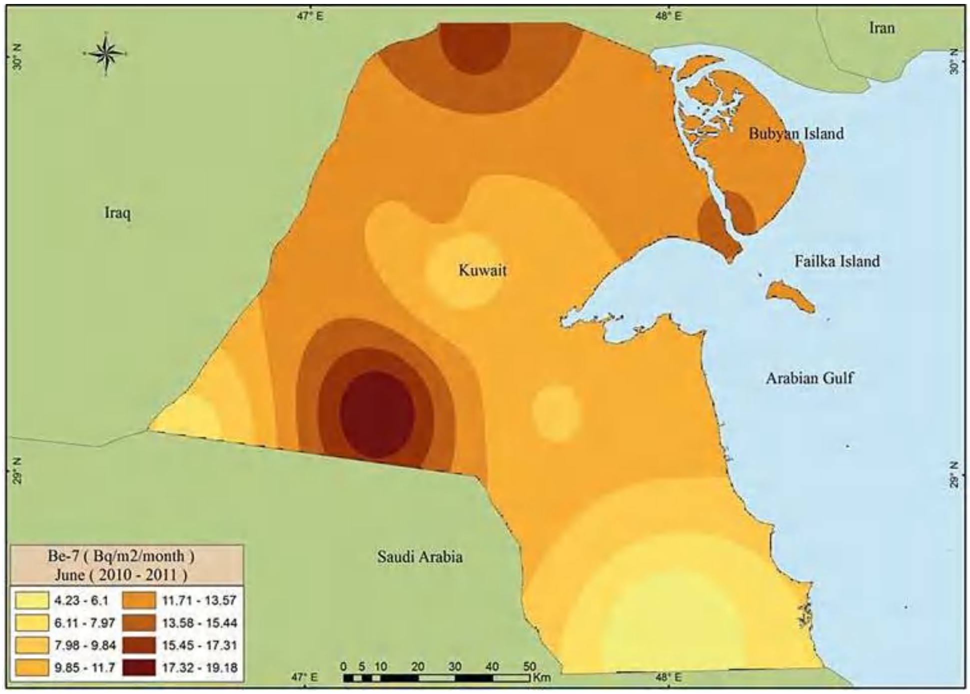


Fig. 6.9 Average deposited rates of ^{7}Be in June (2010–2011)

the southern and eastern areas. The predominant wind direction for this month was northwesterly, with no precipitation events (Fig. 6.9).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Abdulli Ratqah Dibdibah Subiyah Ubayriq	Liyah Wafra Farms Salmi Khiran KhurFawaris

Similar to June, the monthly ^{7}Be deposited rates in Kuwait during July 2010–2011 reveal lower rates than previous months, with a range from 3.71 to 11.78 Bq m^{-2}. The maximum rates were in the northern eastern areas and the lowest in the southern and northeastern areas. The predominant wind direction for this month was northwesterly, with no precipitation events to impact wind from other directions (Fig. 6.10).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Salmi Shegaya Dibdibah Ubayriq Bubiyan Island	Liyah Wafra Farms Huwaymilyah Khiran KhurFawaris

Similar to June and July, the monthly ^{7}Be deposited rates in Kuwait during August 2010–2011 reveal a range from 3.66 to 29.49 Bq m^{-2}, with a maximum in the northern areas and the lowest in the southeastern area (Fig. 6.11).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Abdulli Ratqah Roudhatain Um Niqa Huwaymilyah	Um Madafi' Wafra Farms Subiyah Salmi Atraf

Similar to the summer months, the monthly ^{7}Be deposited rates in Kuwait during September 2010–2011 reveal low rates, ranging from 2.44 to 11.6 Bq m^{-2}, with the maximum in the northern areas and the lowest in the southern and southeastern areas (Fig. 6.12).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Abdulli Ratqah Roudhatain Dibdibah Huwaymilyah	Salmi Wafra Farms Shegaya Khiran KhurFawaris

Similar to the summer months, the monthly ^{7}Be rates deposited in Kuwait during October 2009–2010 reveal a lower rate, ranging from 5.59 to 16.09 Bq m^{-2}, with a maximum in northeast areas, and lowest in the southern areas (Fig. 6.13).

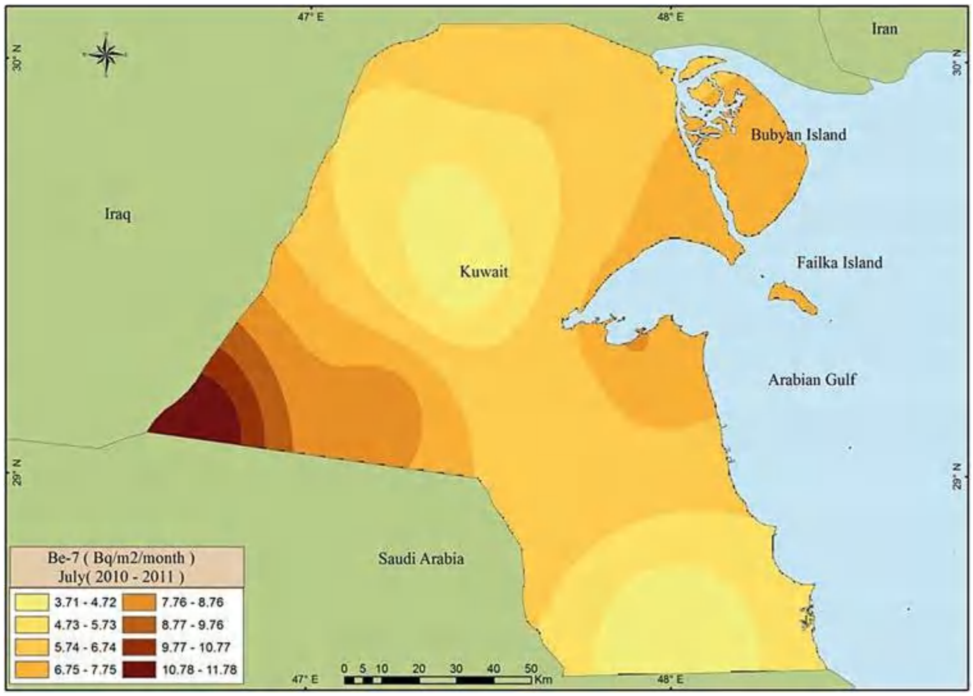


Fig. 6.10 Average deposited rates of ^{7}Be for July (2010–2011)

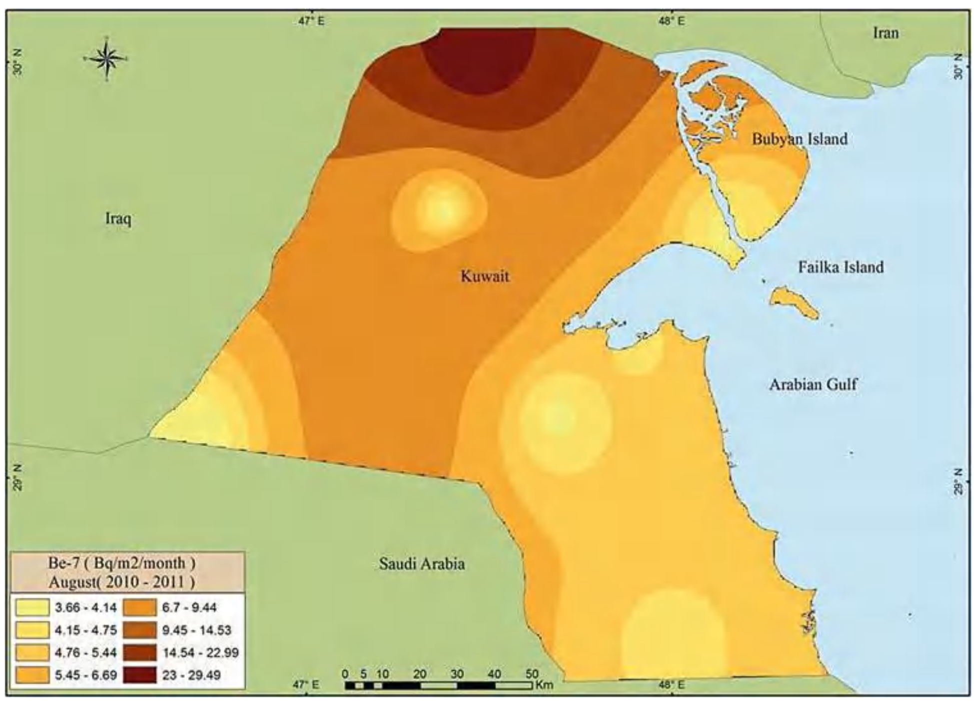


Fig. 6.11 Average deposited rates of ^{7}Be in August (2010–2011)

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Salmi	Liyah
Shegaya	Wafra Farms
Ubayriq	Urayfijan
Dibdibah	Khiran
Salmiya	KhurFawaris

The monthly ^{7}Be deposited rates in Kuwait during November 2009–2010 reveal moderate rates that range from 4.53 to 48.04 Bq m^{-2}, with the maximum in the central areas and the lowest in the southern, northern, and northwestern regions. The predominant wind direction was northwesterly at a minimum speed (Fig. 6.14).

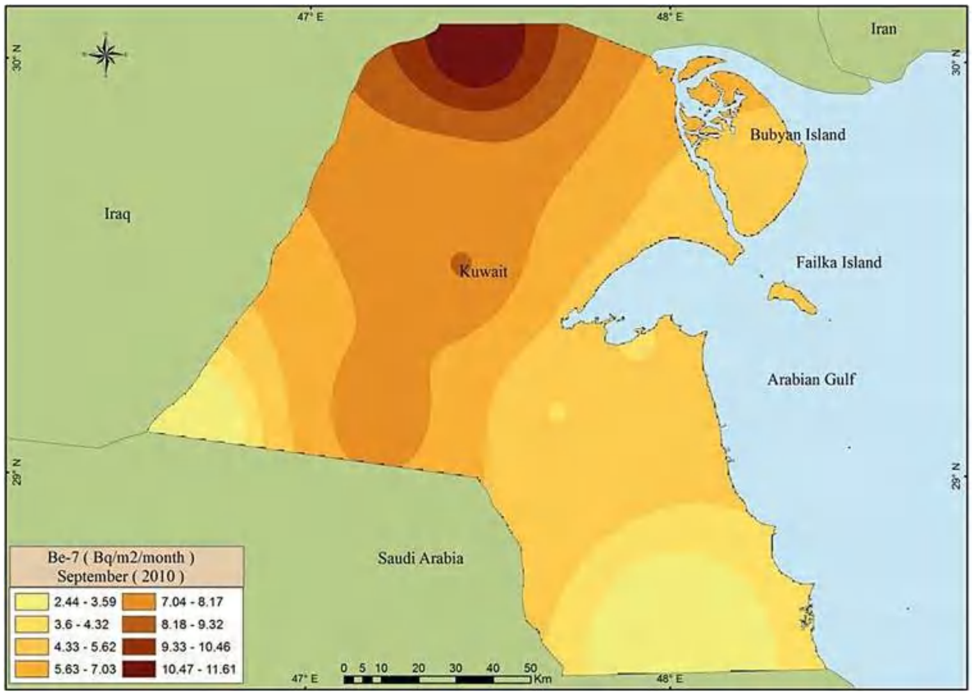


Fig. 6.12 Average percentages of ^{7}Be in September (2010–2011)

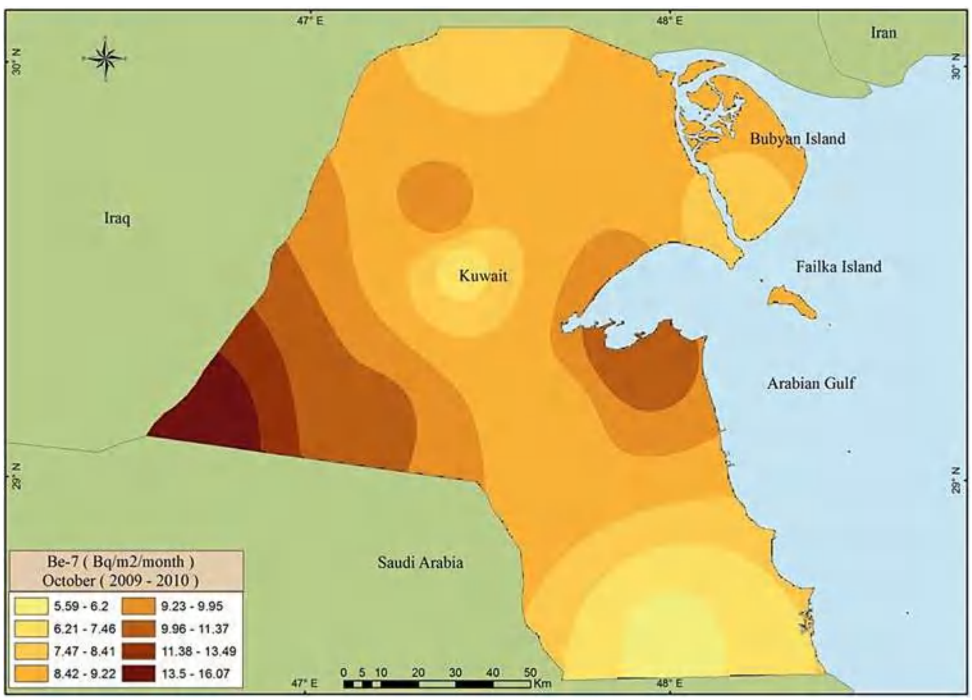


Fig. 6.13 Average deposited rates of ^{7}Be in October (2009–2010)

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Shegaya	Abdulli
Ubayriq	Subiyah
Dibdibah	Urayfijan
Liyah	Khiran
Atraf	KhurFawaris

The monthly ^{7}Be rates deposited in Kuwait during December 2009–2010 reveal moderate rates that range from 3.69 to 46.96 Bq m^{-2}, with the maximum in the central and central western areas and the lowest in the central southern areas. The predominant wind direction was northwesterly at high speed (Fig. 6.15).

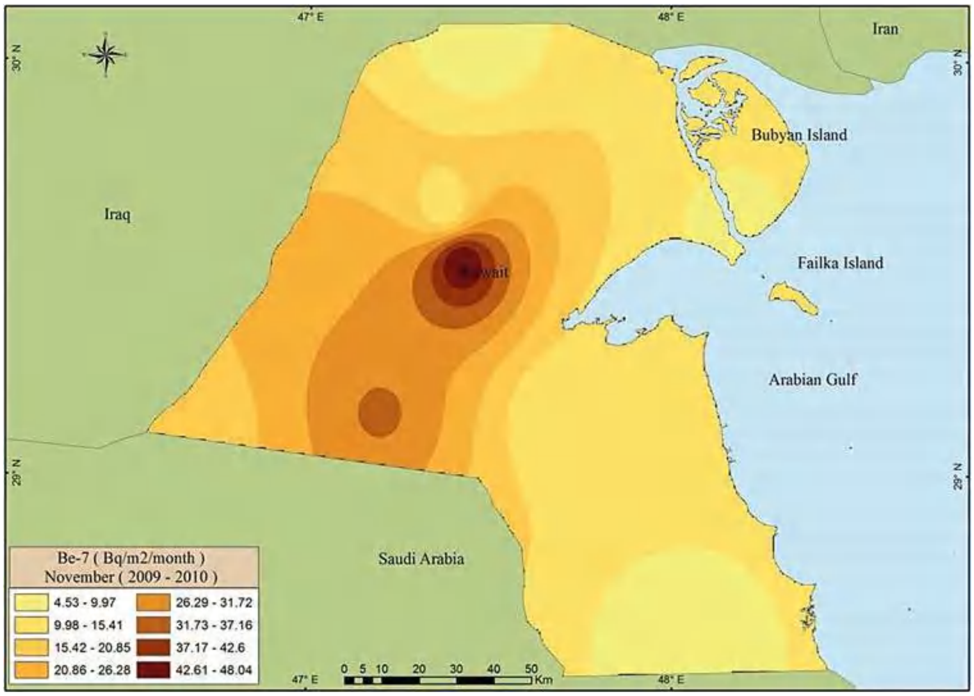


Fig. 6.14 Average deposited rates of ^{7}Be in November (2009–2010)

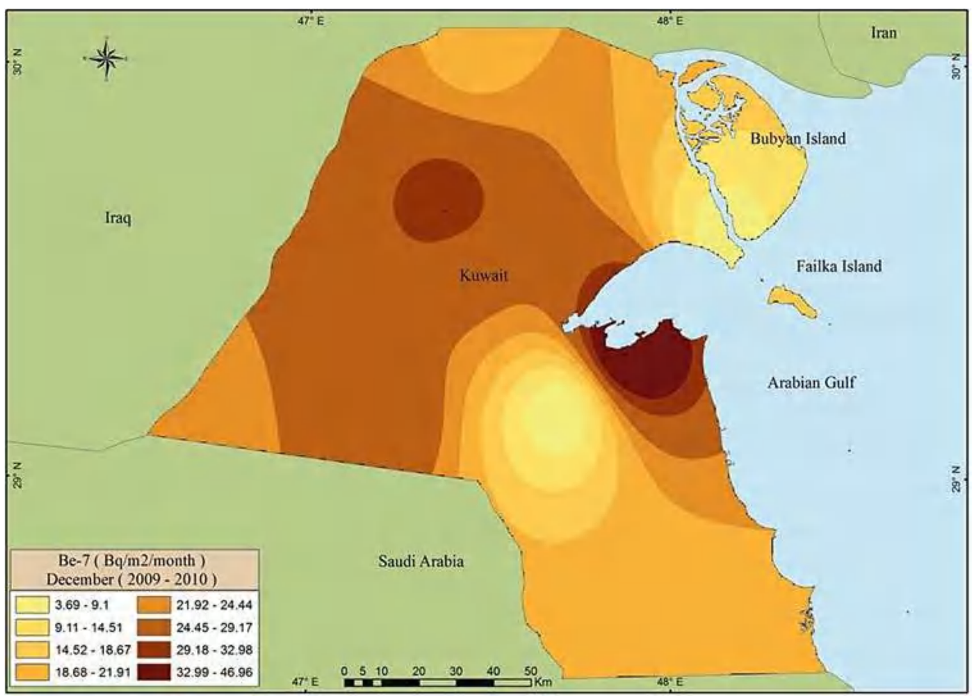


Fig. 6.15 Average deposited rates of ^{7}Be in December (2009–2010)

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Gudhi	Bubiyan Island
Ubayriq	Subiyah
Dibdibah	Sulaybiyah
Liyah	Kabd
Salmiya	Atraf

Annual Deposited Rates of ^{137}Cs

The average annual ^{137}Cs rates deposited in Kuwait from October 2009 to August 2011 varied from 0.2 to 4.18 Bq m^{-2}, with an average of 4.76 Bq m^{-2}. The maximum rates were in southwestern areas. The ^{137}Cs rates deposited gradually decreased from the interior to the coastal areas, where they reached the minimum value. The predominant annual wind direction was northwesterly (Fig. 6.16).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Salmi	Ratqa
Shegaya	Sulaybiyah
Ubayriq	Bubiyan Island
Dibdibah	Subiyah
Um Qudayr	Failaka Island

Monthly Deposited Rates of ^{137}Cs

The monthly ^{137}Cs rates deposited in Kuwait during January 2010–2011 reveal a range from 0.1 to 0.39 Bq m^{-2}, with the maximum in central and southwestern areas and the lowest in southern areas of the Wafra Farms. The predominant wind direction for this month was northwesterly, with high wind speed sometimes (Fig. 6.17).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah	Salmi
Ubayriq	Subiyah
Dibdibah	Sulaybiyah
Um Al Madafi’	Khiran
Ratqah	KhurFawaris

The monthly ^{137}Cs deposited rates in Kuwait during February 2010–2011 varied from 0.21 to 0.54 Bq m^{-2}, with two high deposition rate spots. This possibly happened because of the effect of the dust storms in this month. The predominant wind direction for this month was northwesterly, and the precipitation rates were low (Fig. 6.18).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Salmi	Ratqah
Shegaya	Liyah

(continued)

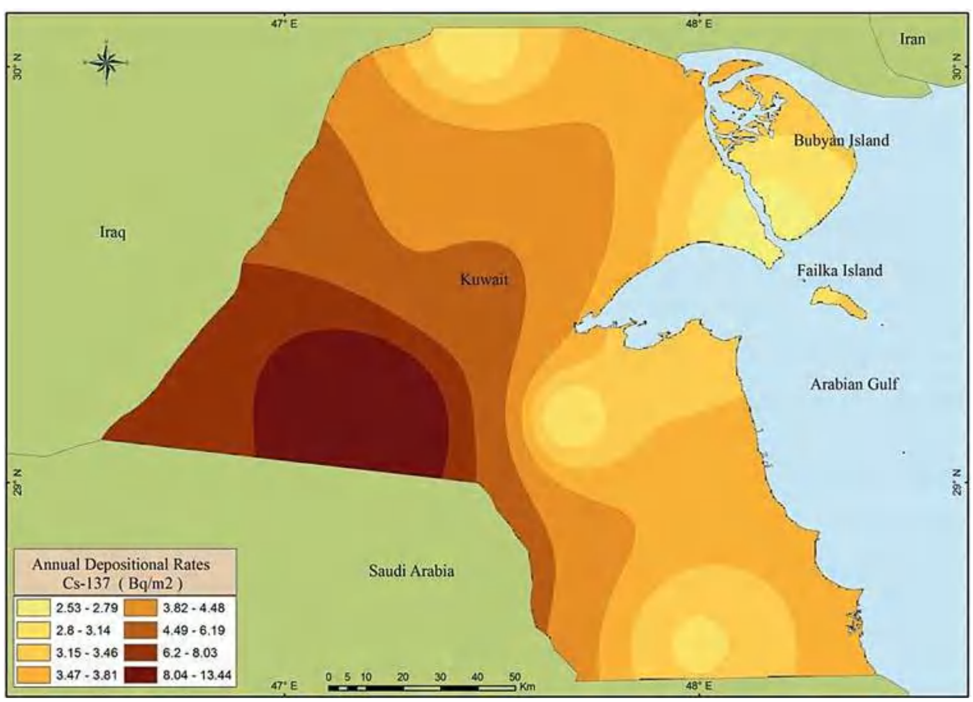


Fig. 6.16 Average deposited rates of ^{137}Cs in (Oct 2009–Aug 2011)

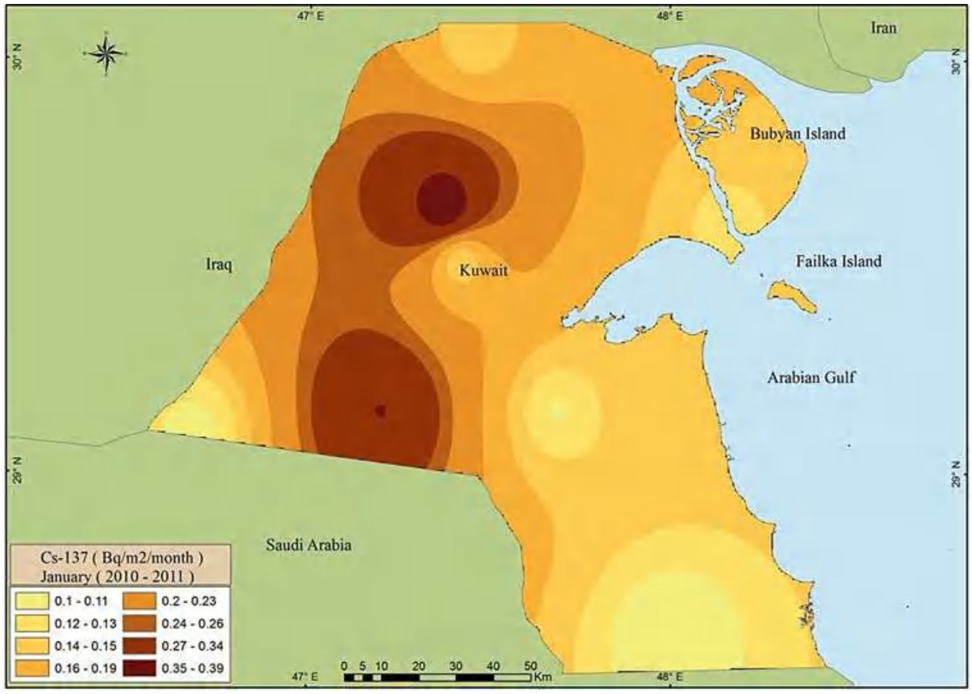


Fig. 6.17 Average deposited rates of ^{137}Cs in January (2010–2011)

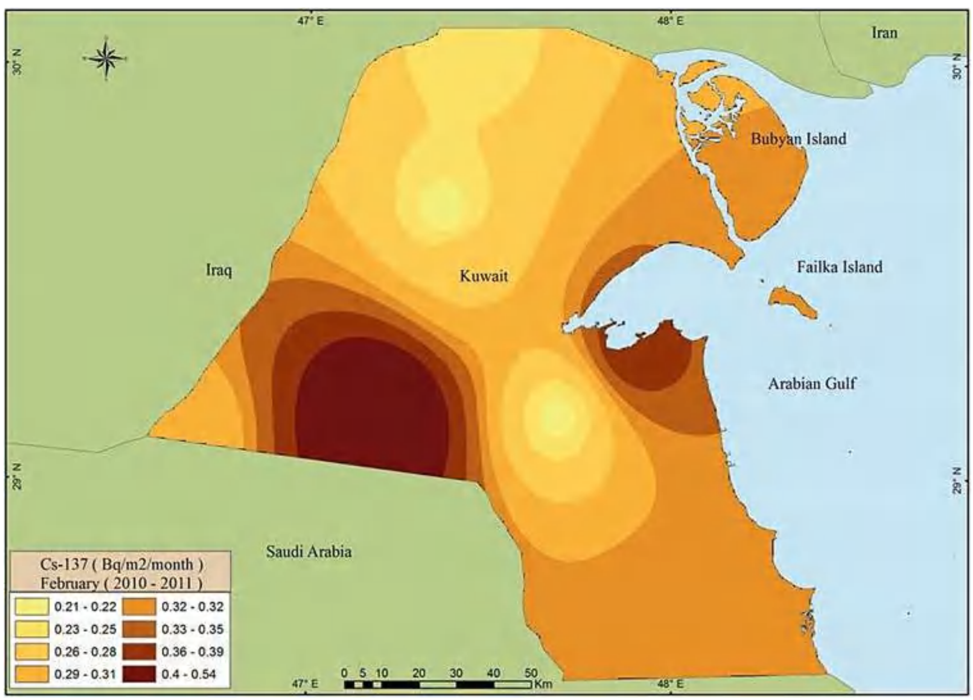


Fig. 6.18 Average deposited rates of ^{137}Cs in February (2010–2011)

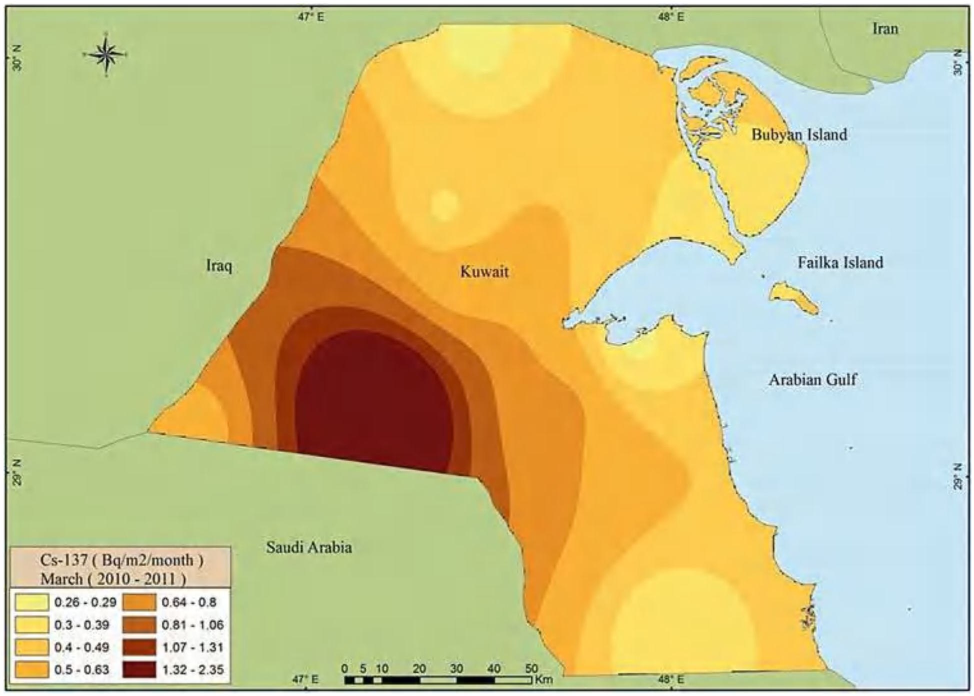


Fig. 6.19 Average deposited rates of ^{137}Cs in March (2010–2011)

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Ubayriq Dibdibah Salmiya	Roudhatain Sulaybiyah Atraf

The monthly ^{137}Cs rates deposited in Kuwait during March 2010–2011 reveal a high range that varied from 0.26 to 2.35 Bq m^{2}, with the maximum in the southwestern area and the lowest in the northern and southern regions. The predominant wind direction for this month was northwesterly, with high speed sometimes. However, the highest deposition flux was reported in this month due to the effect of the exotic storm that hit Kuwait, in addition to the high precipitation recorded (Fig. 6.19).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Kabd Shegaya Ubayriq Dibdibah Um Qudayr	Ratqa Subiyah Bubiyan Island Salmiya Wafra Farms

The monthly ^{137}Cs rates deposited in Kuwait during April 2010–2011 ranged from 0.67 to 1.4 Bq m^{-2}, which is considered high, but it is less than March due to lower precipitation. The predominant wind direction was northwesterly, with a high wind speed of northeasterly, easterly, and southeasterly direction (Fig. 6.20).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Shegaya Ubayriq Dibdibah Huwaymilyah Um Al Madafi’	Subiyah Bubiyan Island Sulaybiyah Kabd Jal Al Zur

The monthly ^{137}Cs rates deposited in Kuwait during May 2010–2011 ranged from 0.22 to 2.23 Bq m^{-2}, with the maximum in the southeastern and central regions. The lowest deposition fluxes were in the southern and eastern areas. However, the slightly high deposition flux in this month was due to the effect of the exotic storm that hit Kuwait on March 25, 2011 (Fig. 6.21).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Shegaya Ubayriq Dibdibah Huwaymilyah Liyah	Subiyah Bubiyan Island Salmiya Wafra Farms Shuaiba

The monthly ^{137}Cs deposited rates in Kuwait during June 2010–2011 display similar rates to previous months, but with lower minimum rates, the range varied from 0.06 to 1.3 Bq m^{-2}. The maximum rates were in southeast areas, and the lowest was in central areas. The predominant wind direction for this month was northwesterly, with no precipitation events (Fig. 6.22).

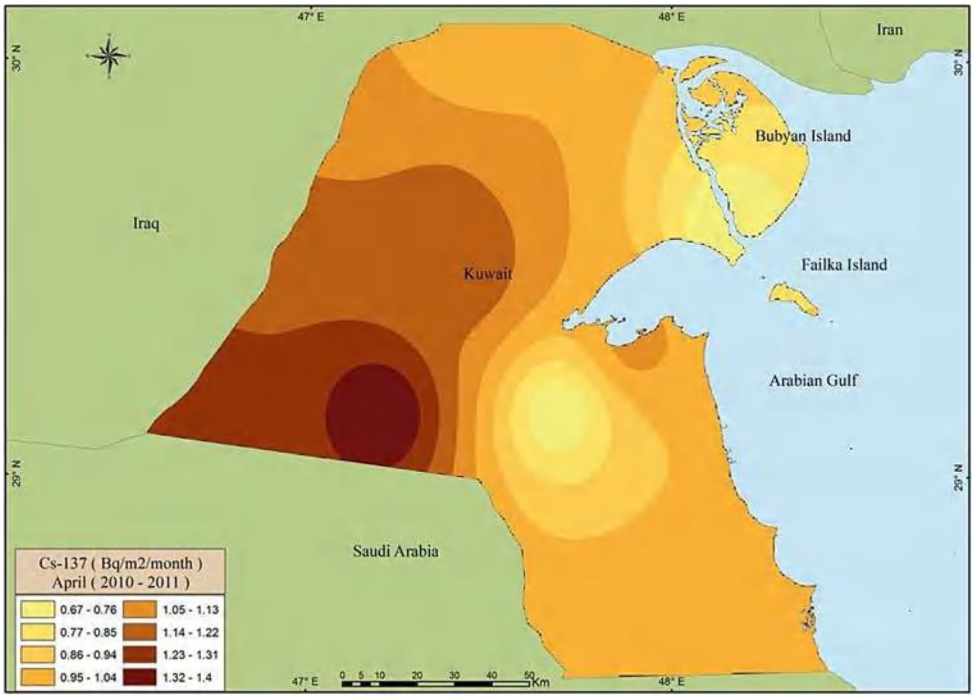


Fig. 6.20 Average deposited rates of ^{137}Cs in April (2010–2011)

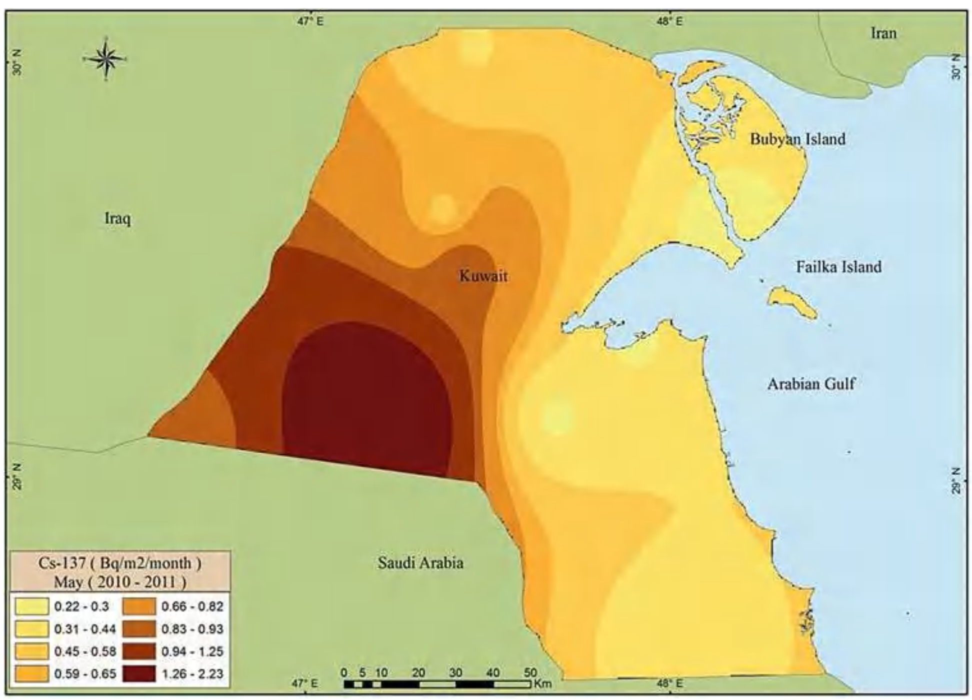


Fig. 6.21 Average deposited rates of ^{137}Cs in May (2010–2011)

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Shegaya	Kabd
Ubayriq	Abdulli
Dibdibah	Atraf
Um Qudayr	Mutla
Liyah	Wafra Farms

The monthly ^{137}Cs rates deposited in Kuwait during July 2010–2011 showed similar rates to the other summer months. The range of deposition flux varied between 0.09 and 1.39 Bq m^{-2}. The maximum rates were in northeastern areas and the lowest in southern and northeastern areas. The predominant wind direction for this month was northwesterly, with no precipitation events that impact wind from other directions (Fig. 6.23).

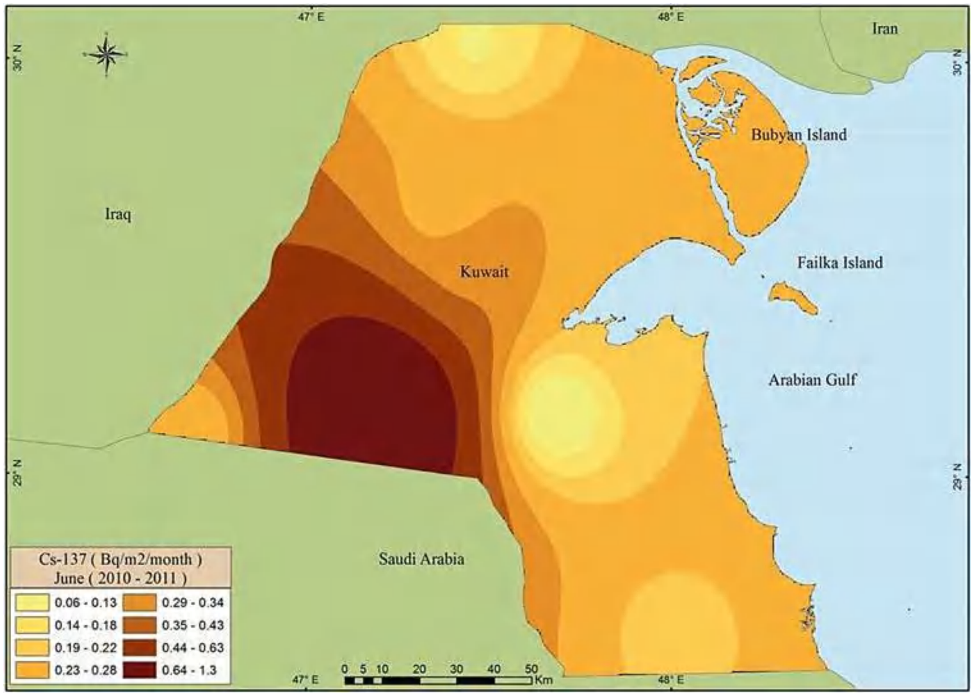


Fig. 6.22 Average deposited rates of ^{137}Cs in June (2010–2011)

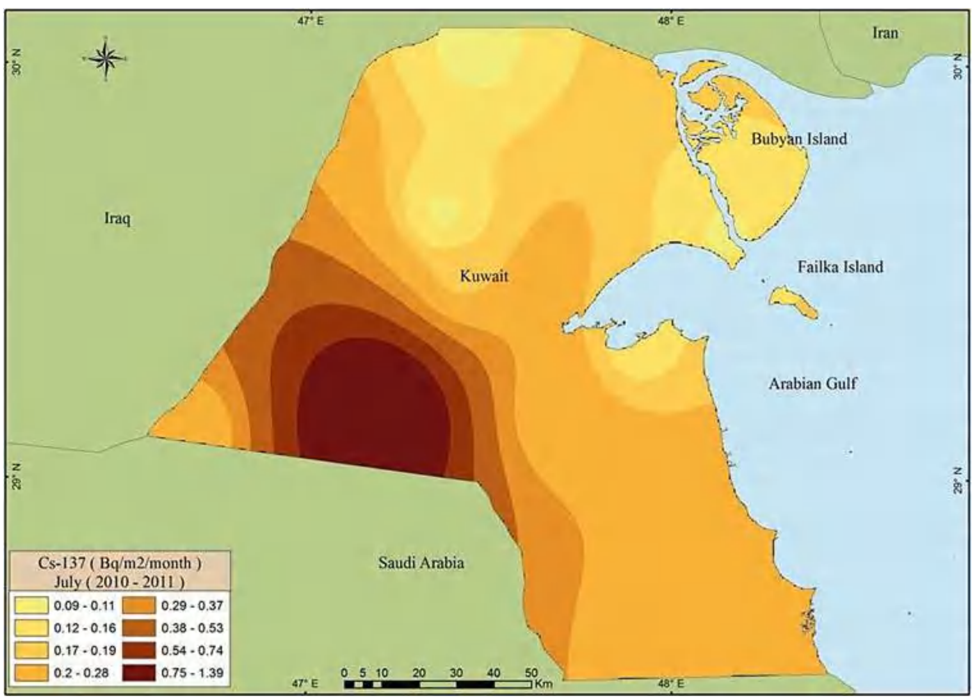


Fig. 6.23 Average deposited rates of ^{137}Cs in July (2010–2011)

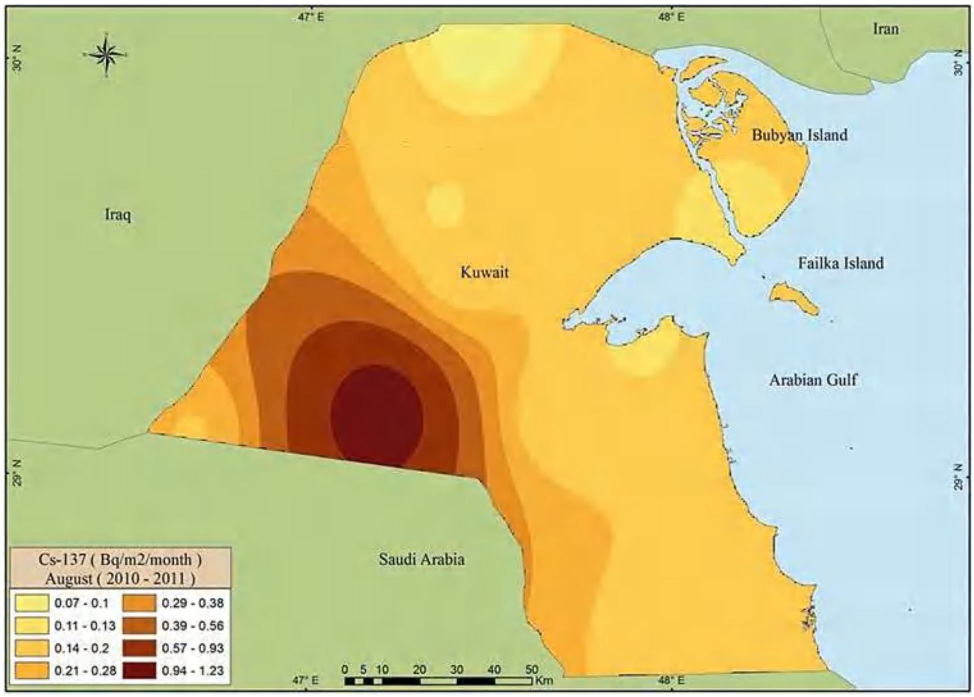


Fig. 6.24 Average deposited rates of ^{137}Cs in August (2010–2011)

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Shegaya Ubayriq Dibdibah Um Qudayr Huwaymilyah	Abdulli Ratqah Um Al Madafi’ Salmiya Bubiyan Island

The monthly ^{137}Cs rates deposited in Kuwait during August 2010–2011 showed similar rates in June and July, with a range that varied from 0.07 to 1.23 Bq m^{-2}, with the maximum in the southwestern areas and the lowest in the southern areas (Fig. 6.24).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Shegaya Ubayriq Dibdibah Um Qudayr Huwaymilyah	Abdulli Ratqah Um Al Madafi’ Salmiya Bubiyan Island

Similar to the summer months, the monthly ^{137}Cs rates deposited in Kuwait during September 2010–2011 ranged from 0.05 to 0.87 Bq m^{-2}, with the maximum in southwestern areas and the lowest in northern and central areas. The predominant wind direction in this month was northwesterly, with no contribution from other directions (Fig. 6.25).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Ubayriq Dibdibah Um Qudayr Liyah	Abdulli Ratqah Um Al Madafi’ Sulaybiyah Wafra Farms

Similar to the summer months, the monthly ^{137}Cs rates deposited in Kuwait during October 2010–2011 ranged from 0.07 to 0.72 Bq m^{-2}, with the maximum in southwestern areas and the lowest in northern and central eastern areas. The predominant wind direction in this month was northwesterly, with no contribution from other directions (Fig. 6.26).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Ubayriq Dibdibah Um Qudayr Salmi	Um Al Madafi’ Sulaybiyah Wafra Farms Salmiya Bubiyan Island

The monthly ^{137}Cs rates deposited in Kuwait during November 2009–2010 showed moderate rates ranging from 0.06 to 1.54 Bq m^{-2}, with the maximum in the central and eastern areas and the lowest in southern areas. The predominant wind direction was northwesterly with minimum speed (Fig. 6.27).

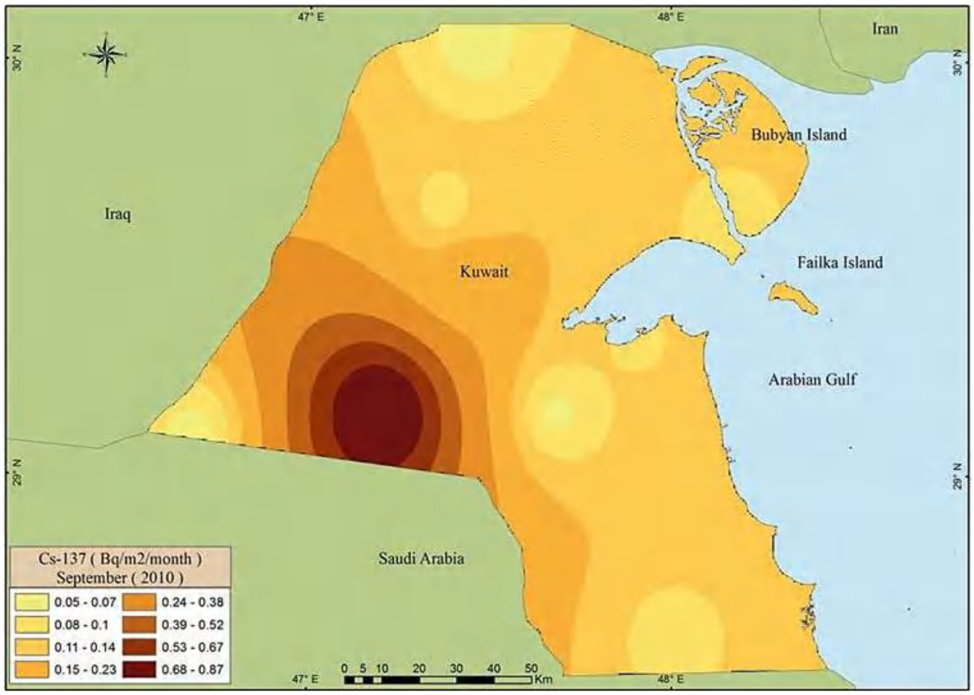


Fig. 6.25 Average deposited rates of ^{137}Cs in September (2010)

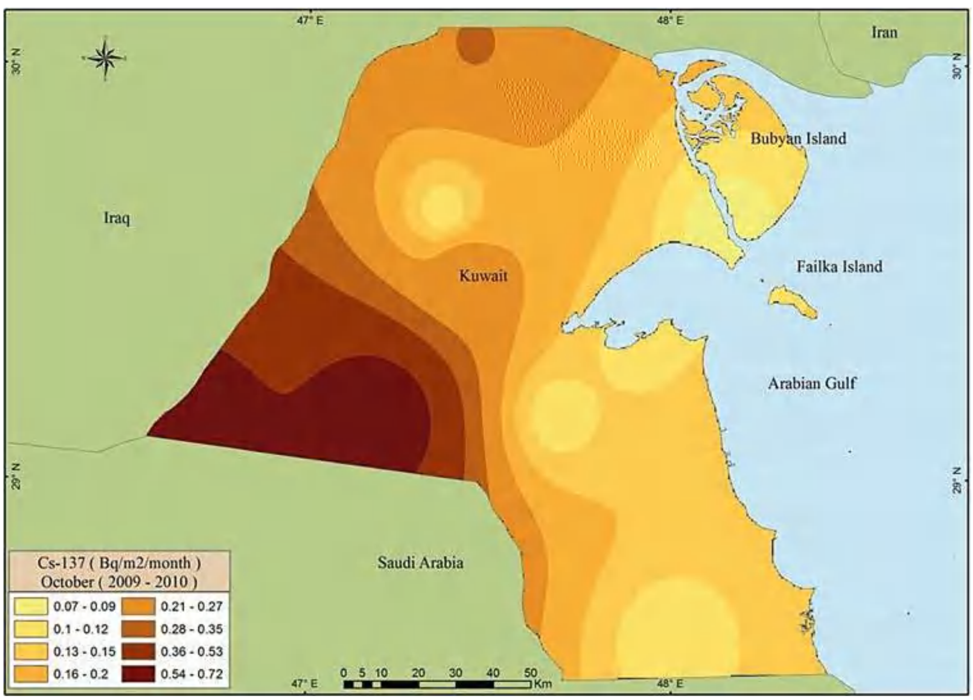


Fig. 6.26 Average deposited rates of ^{137}Cs in October (2009–2010)

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah	Ratqah
Ubayriq	Sulaybiyah
Dibdibah	Wafra Farms
Shegaya	Salmiya
Salmi	Bubiyan Island

The monthly ^{137}Cs rates deposited in Kuwait during December 2009–2010 reveals lower rates than during summer. The deposition rates varied from 0.04 to 0.17 Bq m^{-2}, with the maximum value observed along the transect from the central to southwestern areas. The predominant wind direction was northwesterly, with high speed at times (Fig. 6.28).

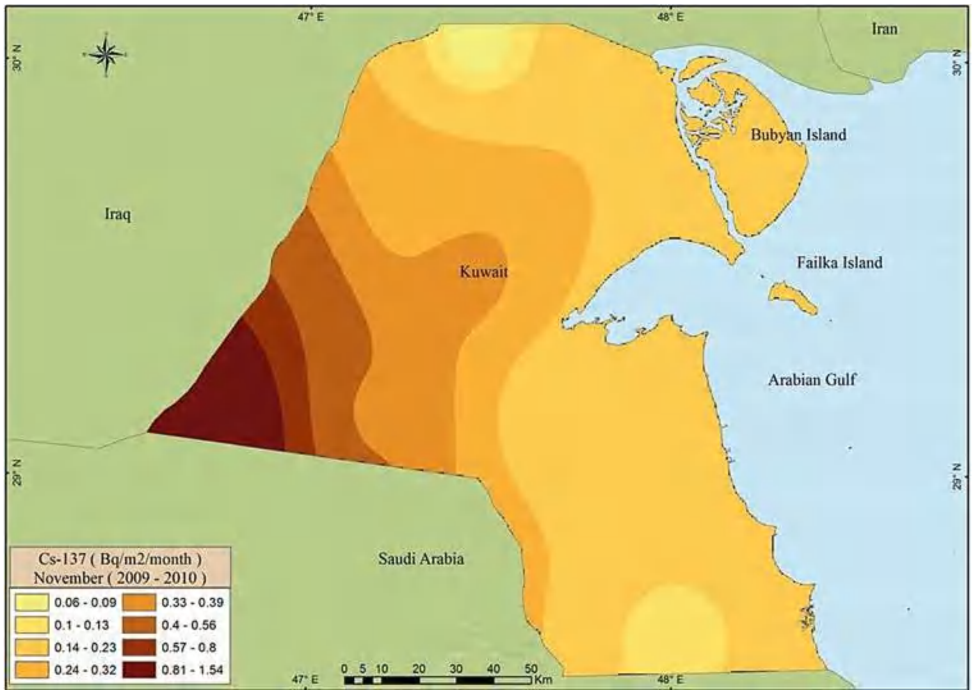


Fig. 6.27 Average deposited rates of ^{137}Cs in November (2009–2010)

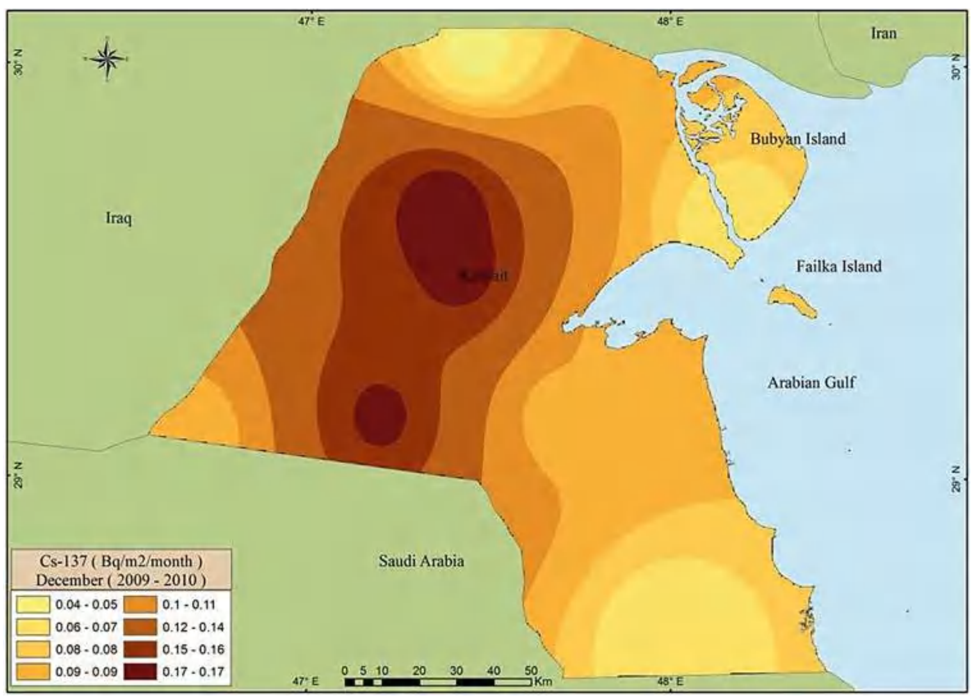


Fig. 6.28 Average deposited rates of ^{137}Cs in December (2009–2010)

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah	Abdulli
Ubayriq	Subiyah
Dibdibah	KhurFawaris
Um Al Madafi'	Khiran
Liyah	Wafra Farms

Annual Deposited Rates of ^{40}K

The average annual ^{40}K deposited rates in Kuwait from October 2009 to August 2011 varied from 74 to 557 Bq m^{-2}, with an average of about 160 Bq m^{-2}. The maximum rates were found in the southwestern areas. The ^{40}K

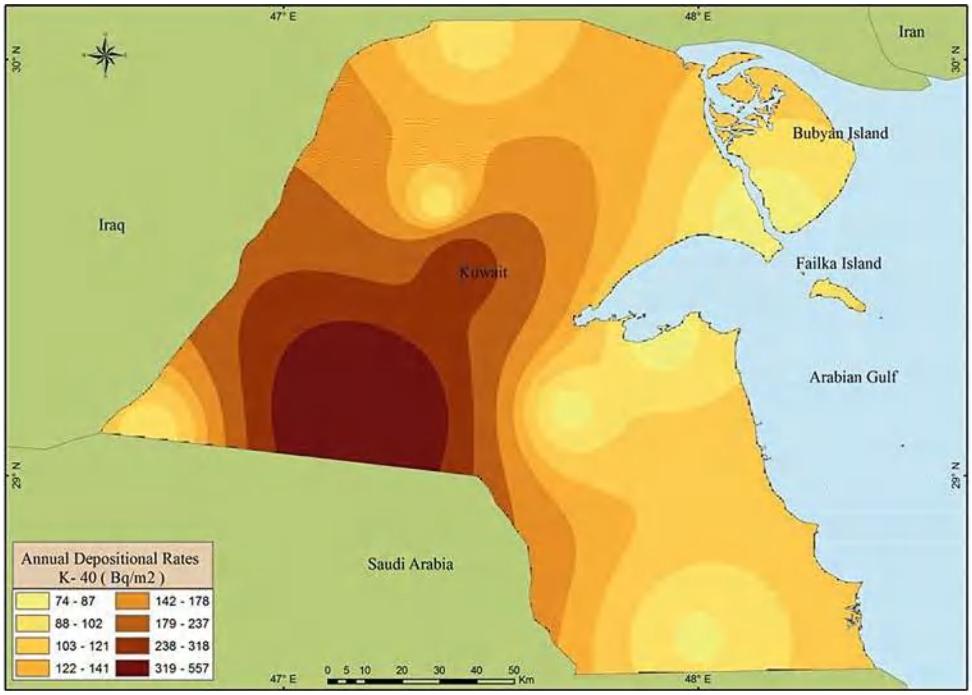


Fig. 6.29 Average deposited rates of ^{40}K in (Oct 2009–Aug 2011)

deposited rates gradually decreased from the interior to the coastal areas, where it reached the minimum. The predominant annual wind direction was northwesterly (Fig. 6.29).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Ubayriq Dibdibah Um Eish Liyah	Abdulli Subiyah Atraf Salmiya Wafra Farms

Monthly Deposited Rates of ^{40}K

The monthly ^{40}K deposited rates in Kuwait during January 2010–2011 ranged from 1.14 to 15.62 Bq m^{-2}, with the maximum in southeastern and western areas, and the lowest was in the central areas. The predominant wind direction for this month was northwesterly, with high wind speed at times (Fig. 6.30).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Ubayriq Dibdibah Salmi Wafra Farms	Abdulli Subiyah Liyah Salmiya Sulaybiyah

The monthly ^{40}K rates deposited in Kuwait during February 2010–2011 varied from 3.13 to 23.0 Bq m^{-2}, with a high deposition rate noted in southeastern areas. This possibly happened because of dust storms that occurred in this month. The predominant wind direction for this month was northwesterly, and the precipitation rates were low (Fig. 6.31).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Ubayriq Dibdibah Liyah Um Qudayr	Abdulli Subiyah Um Al Madafi’ Salmiya Sulaybiyah

The monthly ^{40}K rates deposited in Kuwait during March 2010–2011 had a high range that varied from 5.19 to 96.27 Bq m^{-2}, with the maximum in the southwestern area and the lowest in the northern and southern areas. The predominant wind direction for this month was northwesterly, with high speed registered at times. However, the highest deposition flux was reported in this month because of the effect of the exotic storm that hit Kuwait, in addition to high precipitation (Fig. 6.32).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Ubayriq Dibdibah Liyah Um Qudayr	Abdulli Subiyah Wafra Farms Salmiya Bubiyan Island

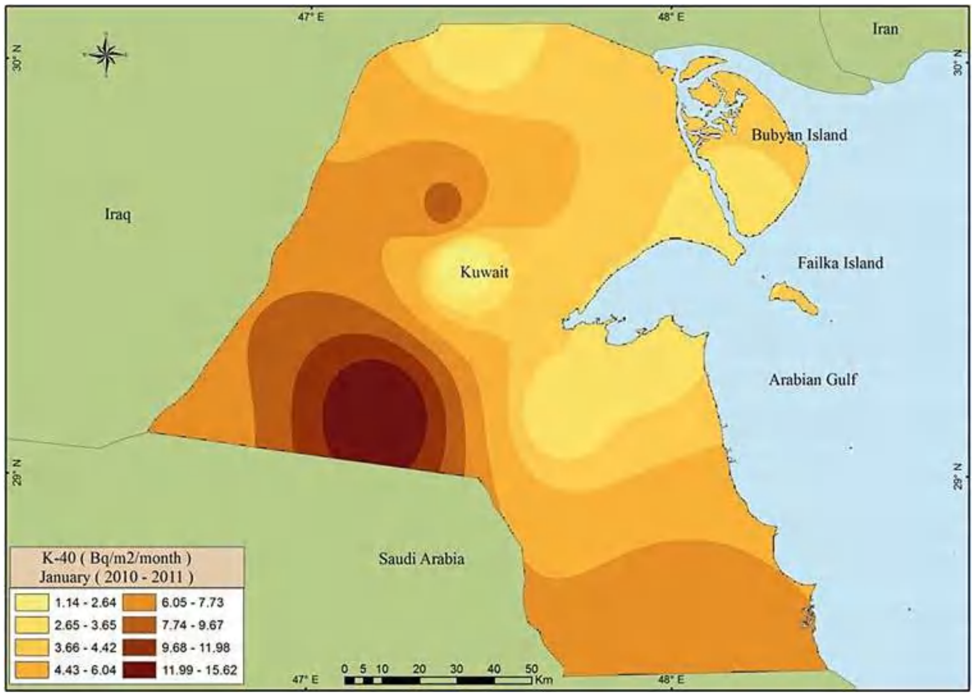


Fig. 6.30 Average deposited rates of ^{40}K in January (2010–2011)

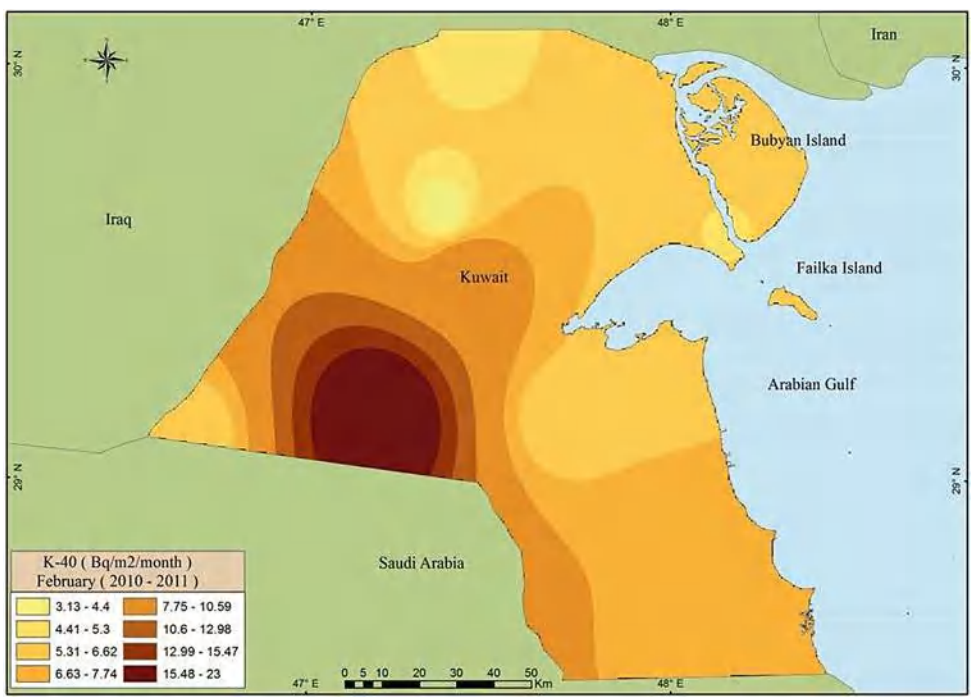


Fig. 6.31 Average deposited rates of ^{40}K in February (2010–2011)

The monthly ^{40}K rates deposited in Kuwait during April 2010–2011 ranged from 12.88 to 69.77 Bq m^{-2}, which is considered high but is lower than the rates in March due to lower precipitation rates. A spot with high deposition rates was found in the central areas. The predominant wind direction was northwesterly, with a high wind speed of northeastern, eastern, and southeastern wind contribution. The critical dynamic weather due to Koss and Sarrayat that occurred in spring contributed toward the high deposition rates (Fig. 6.33).

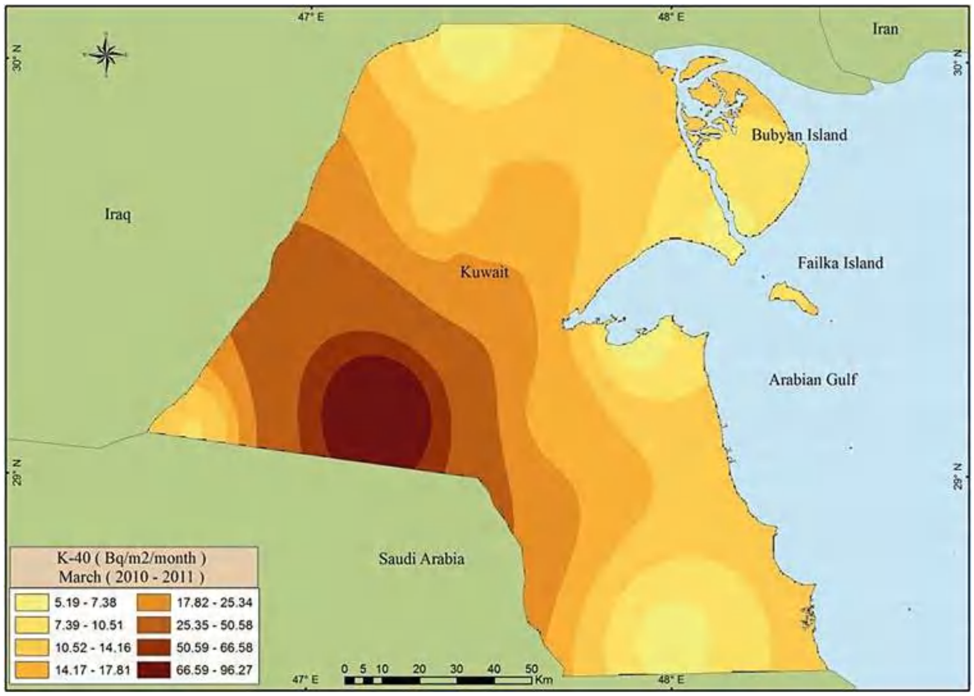


Fig. 6.32 Average deposited rates of ^{40}K in March (2010–2011)

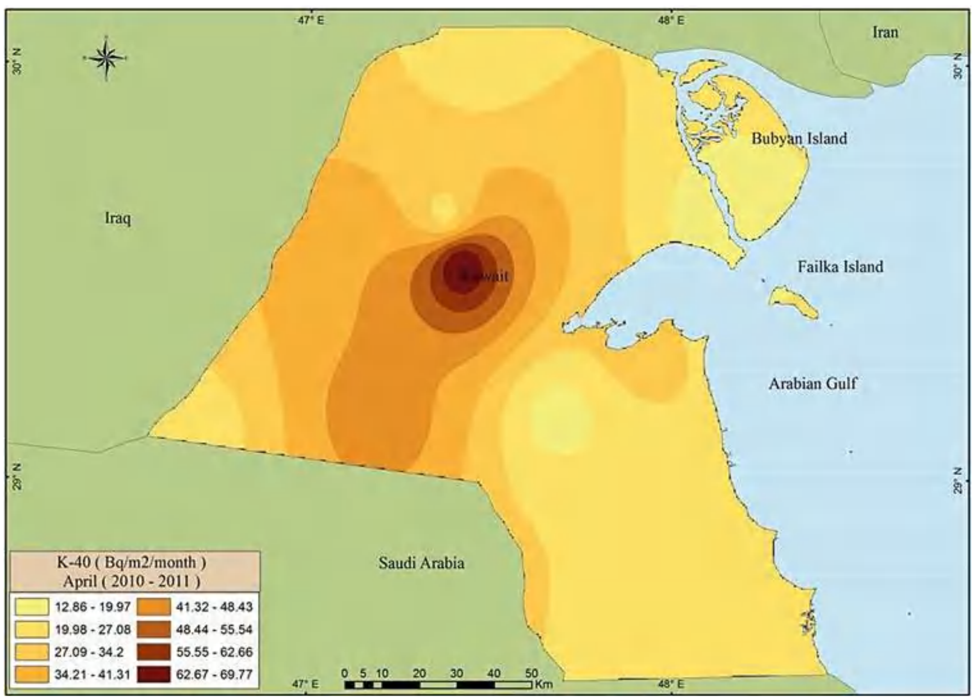


Fig. 6.33 Average deposited rates of ^{40}K in April (2010–2011)

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah	Abdulli
Ubayriq	Subiyah
Dibdibah	Wafra Farms
Liyah	Shuaiba
Gudhi	Bubiyan Island

The monthly ^{40}K rates deposited in Kuwait during May 2010–2011 ranged from 5.12 to 70.63 Bq m^{-2}, with the maximum in southeastern and central areas. This range is similar to the other spring months, in which the critical dynamics weather due to Koss and Sarrayat contributed toward high deposition rates. The lowest deposition fluxes were in southern and eastern areas. However, the high

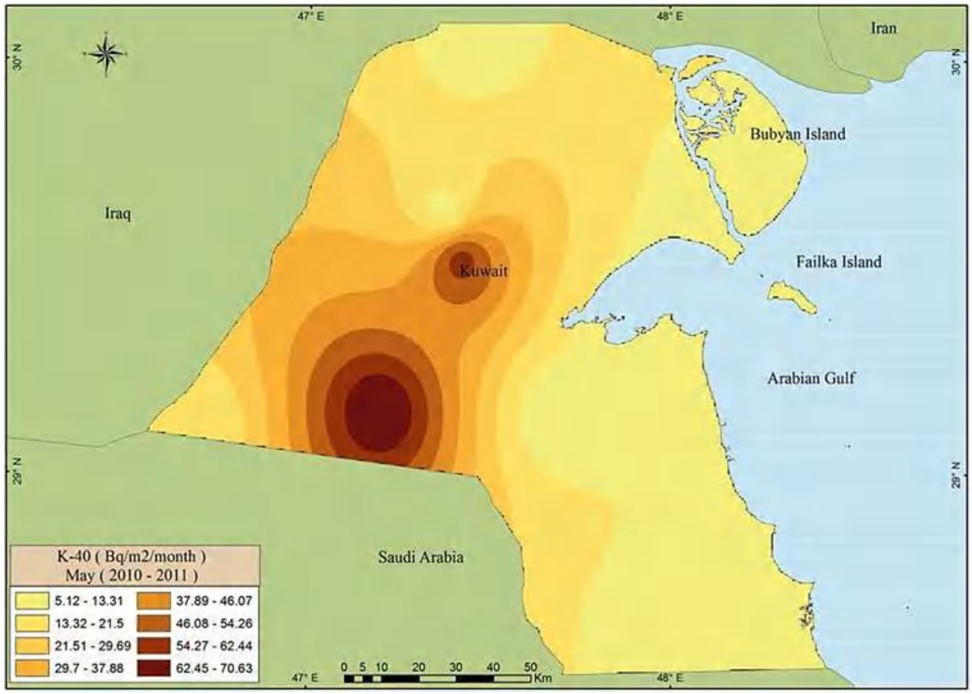


Fig. 6.34 Average deposited rates of ^{40}K in May (2009–2010)

deposition flux this month was due to the effect of the exotic storm that hit Kuwait on March 25, 2011 (Fig. 6.34).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Ubayriq Dibdibah Liyah Kabd	Abdulli Jal Al Zur Wafra Farms Shuaiba Bubiyan Island

The monthly ^{40}K deposited rates in Kuwait during June 2010–2011 had similar rates as previous months, but with lower minimum rates, the range varied from 4.53 to 60.43 Bq m^{-2}. The maximum rates were in southeastern areas, and the lowest was in coastal areas. The predominant wind direction for this month was northwesterly, with no precipitation events (Fig. 6.35).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Ubayriq Dibdibah Liyah Um Qudayr	Abdulli Salmi Salmiya Sulaybiyah Kabd

The monthly ^{40}K rates deposited in Kuwait during July 2010–2011 were similar to the other summer months. The range of deposition varied between 2.31 and 61.76 Bq m^{-2}. The maximum rates were in southeastern areas, and the lowest rates were in southern and northeastern areas. The predominant wind direction for this month was northwesterly, with no precipitation events or impact wind from other directions (Fig. 6.36).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Ubayriq Dibdibah Liyah Um Qudayr	Abdulli Subiyah Salmiya Salmi Bubiyan Island

The monthly ^{40}K rates deposited in Kuwait during August 2010–2011 had a similar trend to June and July, with a low range that varied from 2.23 to 27.63 Bq m^{-2}, with the maximum in southwestern areas. The predominant wind direction was northwesterly, with a minor contribution made by southeastern wind (Fig. 6.37).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Ubayriq Dibdibah Liyah Bubiyan Island	Abdulli Salmi Salmiya Sulaybiyah Wafra Farms

Similar to the summer months, the monthly ^{40}K rates deposited in Kuwait during September 2010–2011 ranged from 1.55 to 41.61 Bq m^{-2}, with the maximum recorded in southwestern areas and the lowest recorded in northern and central coastal areas. The predominant wind direction in this

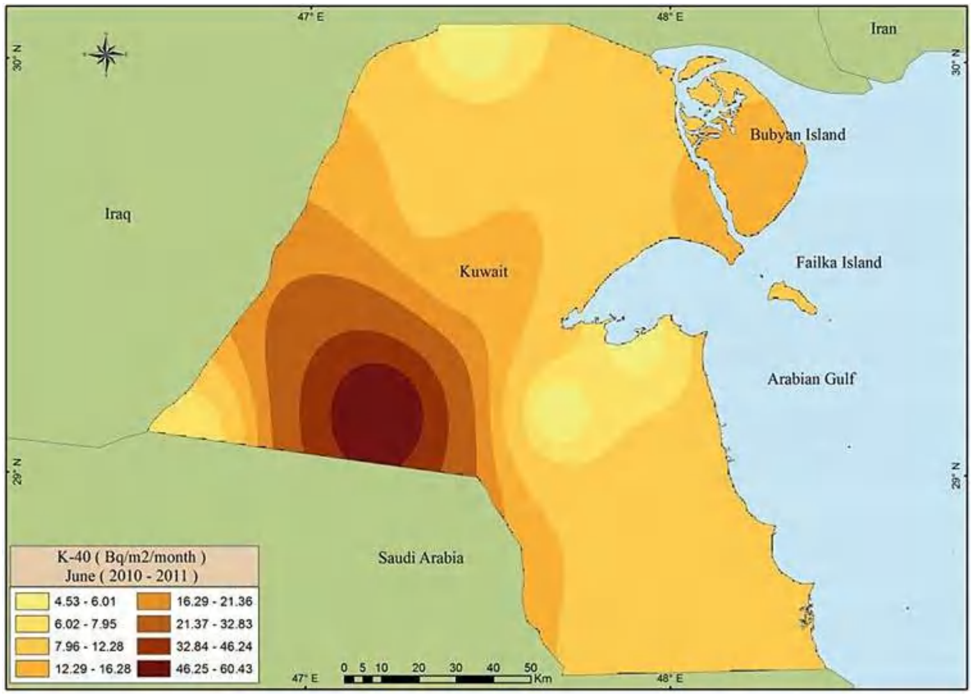


Fig. 6.35 Average deposited rates of ^{40}K in June (2010–2011)

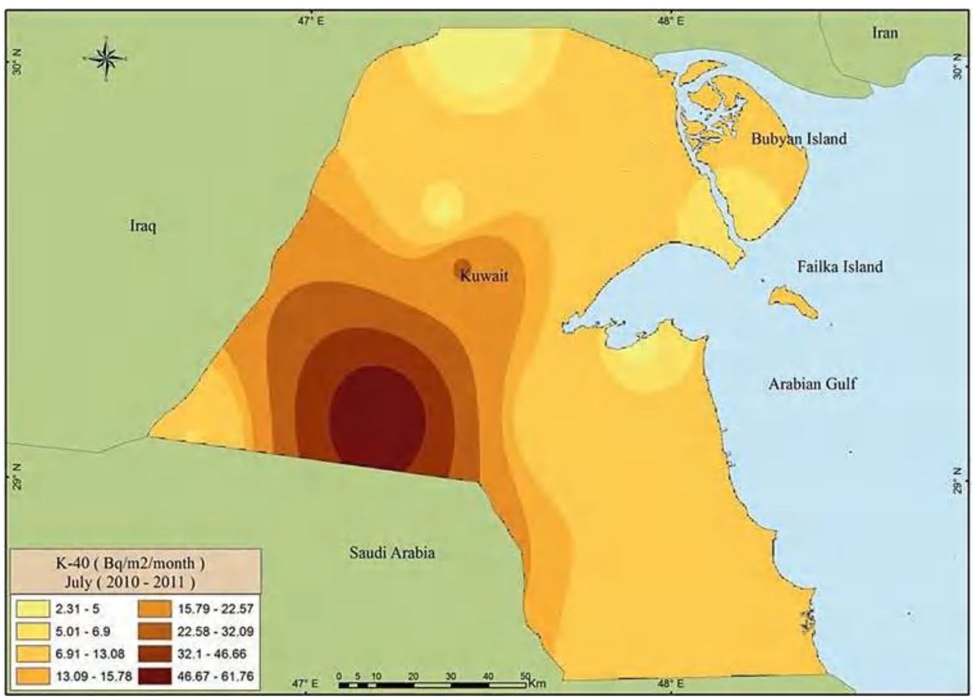


Fig. 6.36 Average deposited rates of ^{40}K in July (2010–2011)

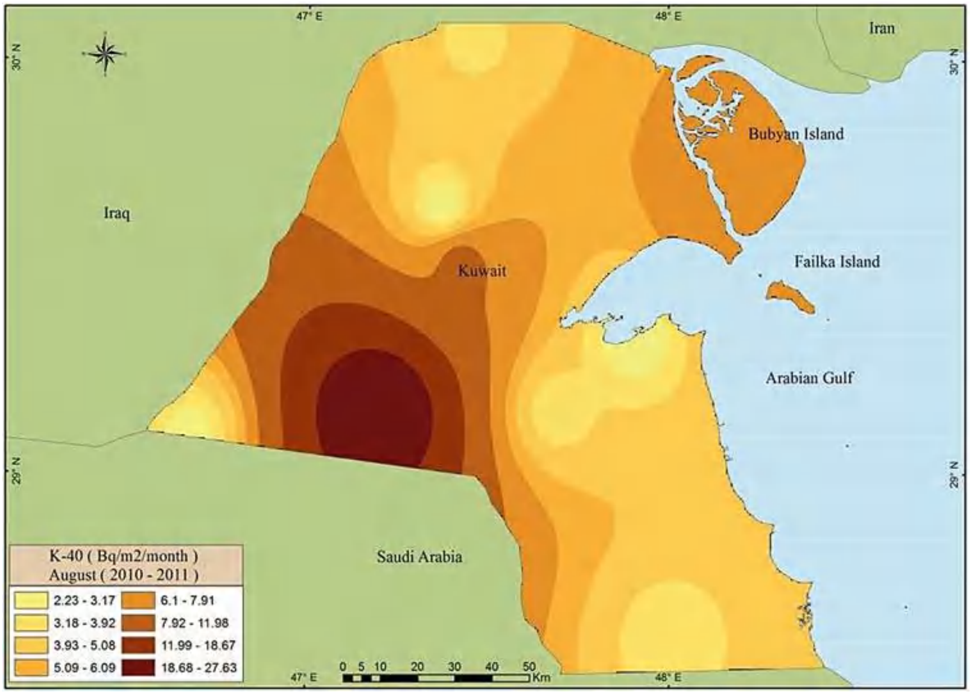


Fig. 6.37 Average deposited rates of ^{40}K in August (2010–2011)

month was northwesterly, with no contribution from other directions (Fig. 6.38).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Ubayriq Dibdibah Liyah Shegaya Huwaymilyah	Abdulli Salmi Salmiya Bubiyan Island Wafra Farms

Similar to summer, the monthly ^{40}K rates deposited in Kuwait during October 2010–2011 ranged from 1.56 to 61.32 Bq m^{-2}, with the maximum in southwestern areas and the lowest in northern and central eastern areas. The predominant wind direction of this month was northwesterly, with no contribution from other directions (Fig. 6.39).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Ubayriq Dibdibah Liyah Ratqah Huwaymilyah	Subiyah Salmi Salmiya Bubiyan Island Wafra Farms

The monthly ^{40}K rates deposited in Kuwait during November 2009–2010 were low, ranging from 1.28 to 21.28 Bq m^{-2}, with the maximum in the central and southwestern areas and the lowest in the southern and northern areas. The predominant wind direction was northwesterly, with high speed recorded at times (Fig. 6.40).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Ubayriq Dibdibah Liyah Shegaya Huwaymilyah	Abdulli Subiyah Salmiya Bubiyan Island Wafra Farms

The monthly ^{40}K rates deposited in Kuwait during December 2009–2010 were moderate and ranged from 1.91 to 31.12 Bq m^{-2}, with the maximum in the southwestern areas and the lowest in the southern areas. The predominant wind direction was northwesterly, with high speed at times (Fig. 6.41).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Ubayriq Dibdibah Liyah Shegaya Huwaymilyah	Abdulli Subiyah Salmi Bubiyan Island Wafra Farms

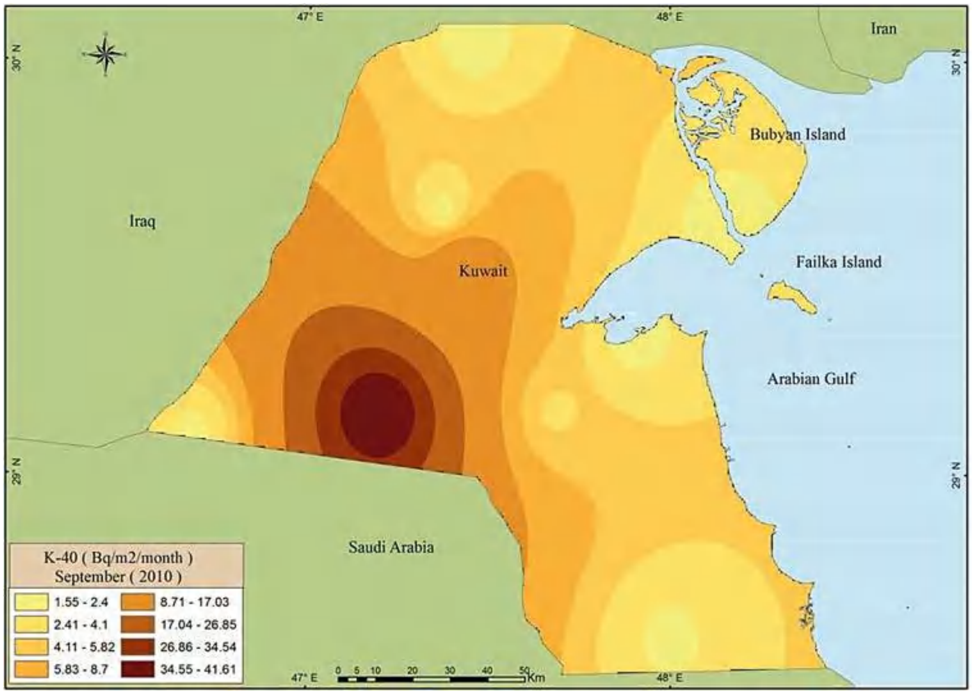


Fig. 6.38 Average deposited rates of ^{40}K in September (2010)

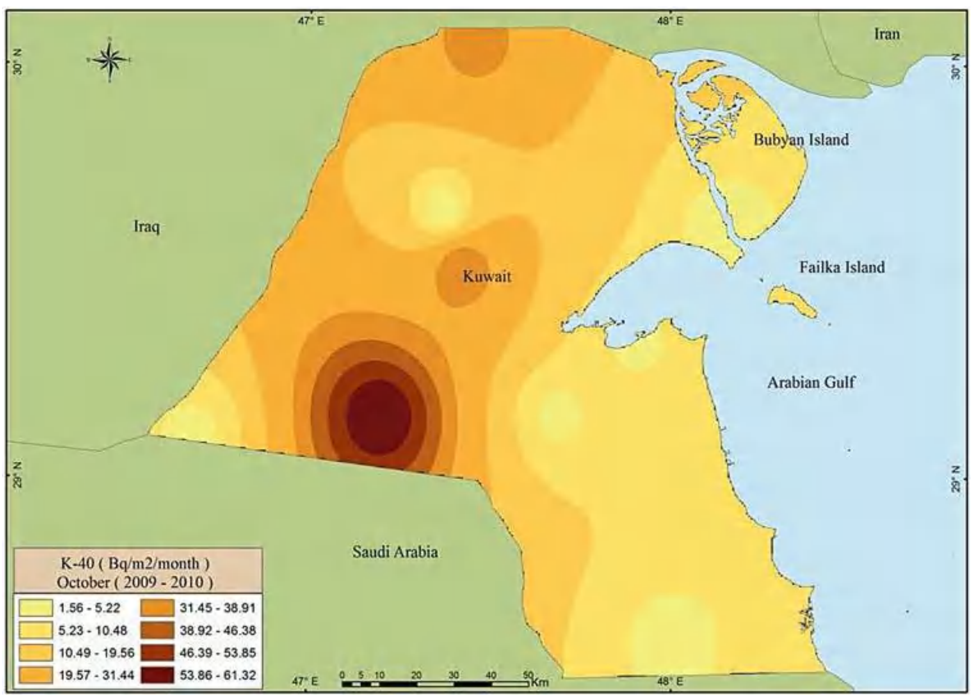


Fig. 6.39 Average deposited rates of ^{40}K in October (2009–2010)

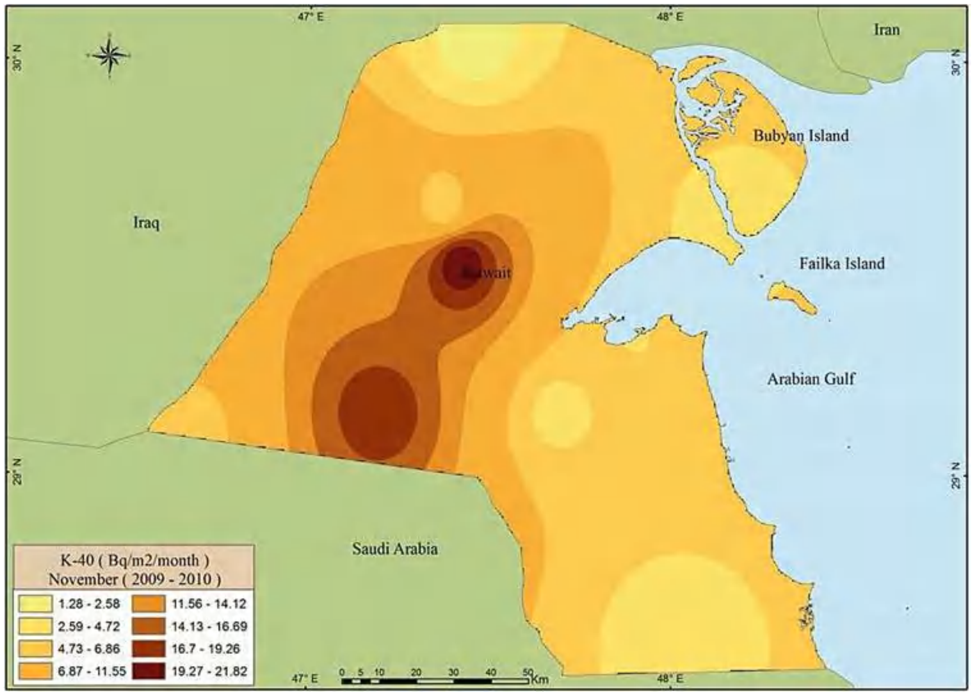


Fig. 6.40 Average deposited rates of ^{40}K in November (2009–2010)

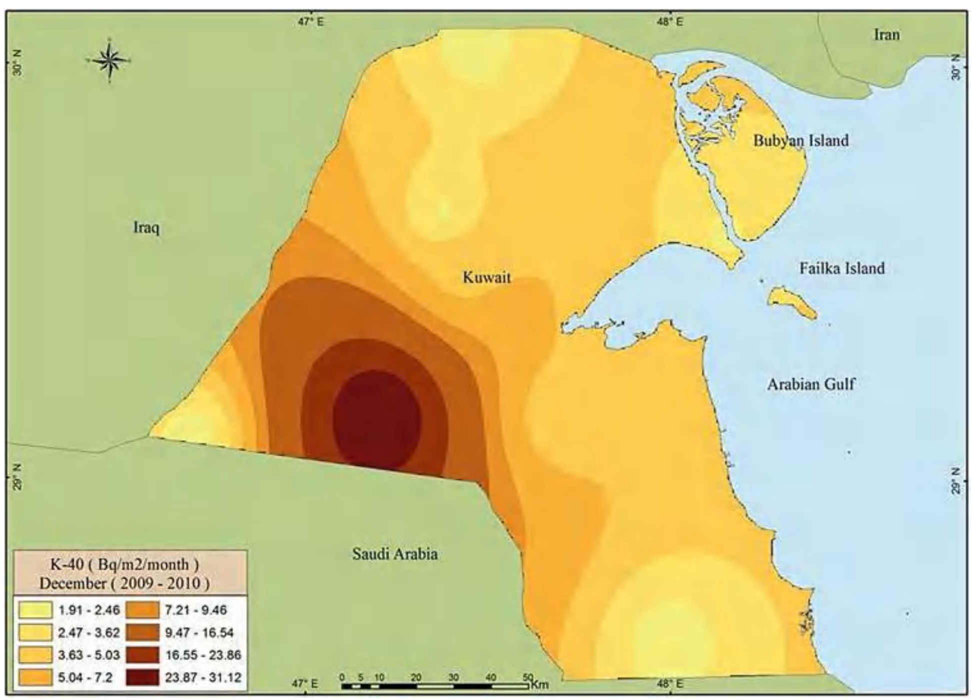


Fig. 6.41 Average deposited rates of ^{40}K in December (2009–2010)

Annual Deposited Rates of ^{210}Pb

The average annual ^{210}Pb rates deposited in Kuwait from October 2009 to August 2011 varied from 107 to 233 Bq m^{-2}, with an average of about 134 Bq m^{-2}, which is close to the reported ^{210}Pb annual deposition rates on the continent between 10° and 30° N latitude (160 Bq m^{-2}). The maximum rates were in the southeastern part of the country (Shaqaya). The minimum rates were along the coastal areas. A maximum of ^{210}Pb deposition flux was revealed in the spring months; when the precipitation was high, the predominant annual wind direction was northwesterly (Fig. 6.42).

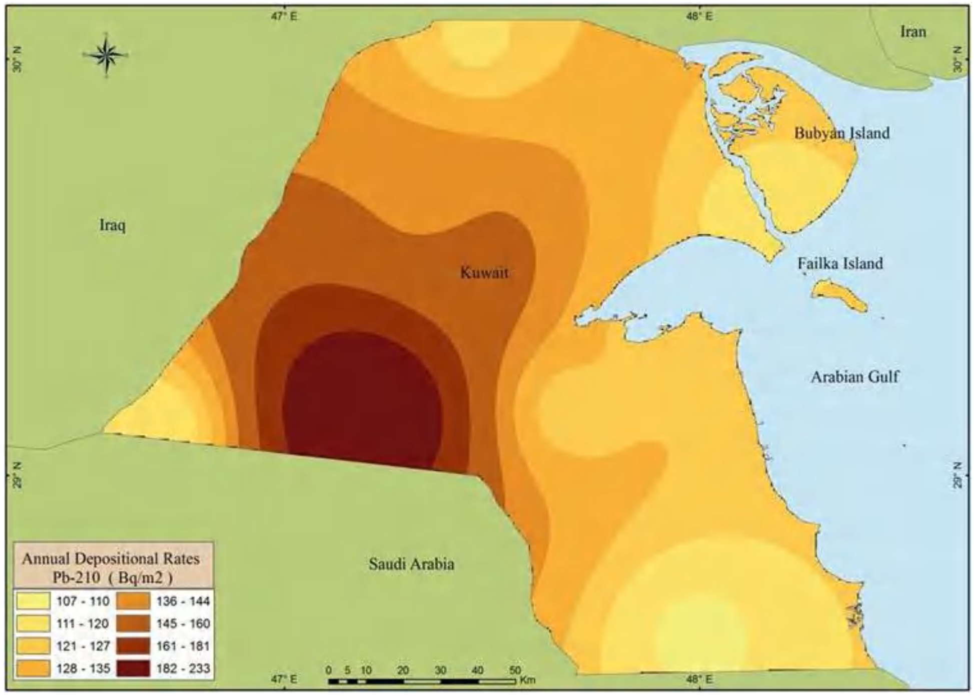


Fig. 6.42 Average deposited rates of ^{210}Pb in (October 2009–August 2011)

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Ubayriq Dibdibah Liyah Shegaya Huwaymilyah	Abdulli Subiyah Salmi Bubiyan Island Wafra Farms

Monthly Deposited Rates of ^{210}Pb

The monthly ^{210}Pb deposited rates in Kuwait during January 2010–2011 ranged from 4.9 to 16.73 Bq m^{-2}, with the maximum in central areas and the lowest in southern areas. The predominant wind direction for this month was northwesterly (Fig. 6.43).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Dibdibah Liyah Ratqah Um Al Madafi'	Salmi Sulaybiyah KhurFawaris Khiran Wafra Farms

The monthly ^{210}Pb rates deposited in Kuwait during February 2010–2011 ranged from 9.39 to 16.6 Bq m^{-2}, with three maximum spots. This is possibly visible because of the effect of dust storms this month. The predominant wind direction for this month was northwesterly, and the precipitation rates were lower (Fig. 6.44).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Bubiyan Island Dibdibah Liyah Ratqah Subiyah	Salmi Sulaybiyah Liyah Atraf Kabd

The monthly ^{210}Pb deposited rates in Kuwait during February 2010–2011 ranged from 9.39 to 16.6 Bq m^{-2}, with three maximum spots. This is possibly visible because of the effect of dust storms this month. The predominant wind direction for this month was northwesterly, and the precipitation rates were lower (Fig. 6.45).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Dibdibah Liyah Ubayriq Um Al Madafi'	Salmi Subiyah Ratqah Salmiya Wafra Farms

The monthly ^{210}Pb deposited rates in Kuwait during April 2010–2011 ranged from 22.36 to 41.38 Bq m^{-2}. The major parameter affecting this high value was the high precipitation rate. The predominant wind direction was northwesterly,

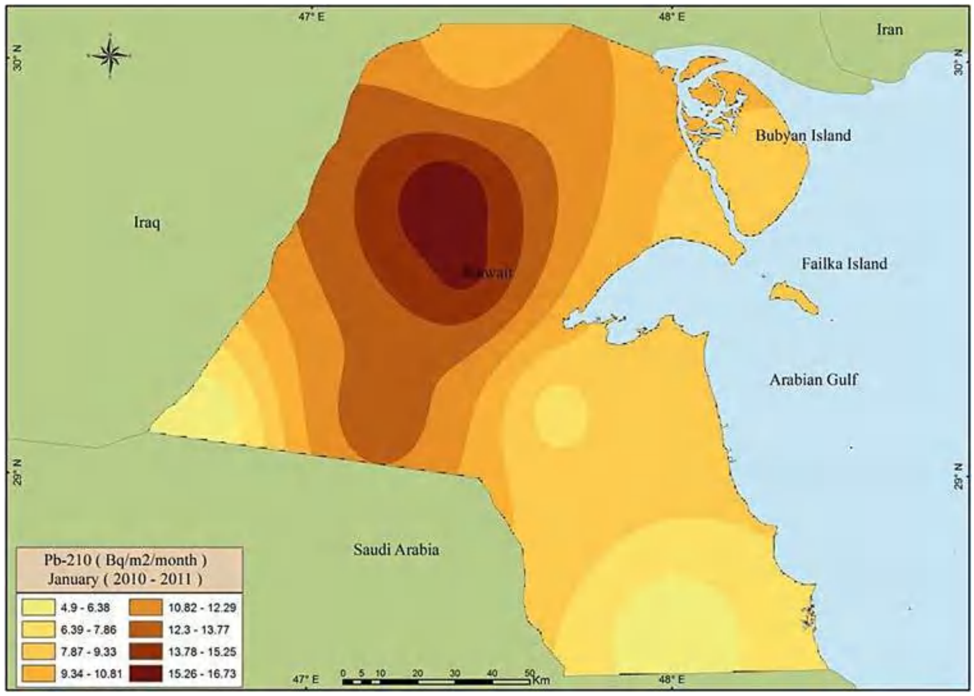


Fig. 6.43 Average deposited rates of ^{210}Pb in January (2010–2011)

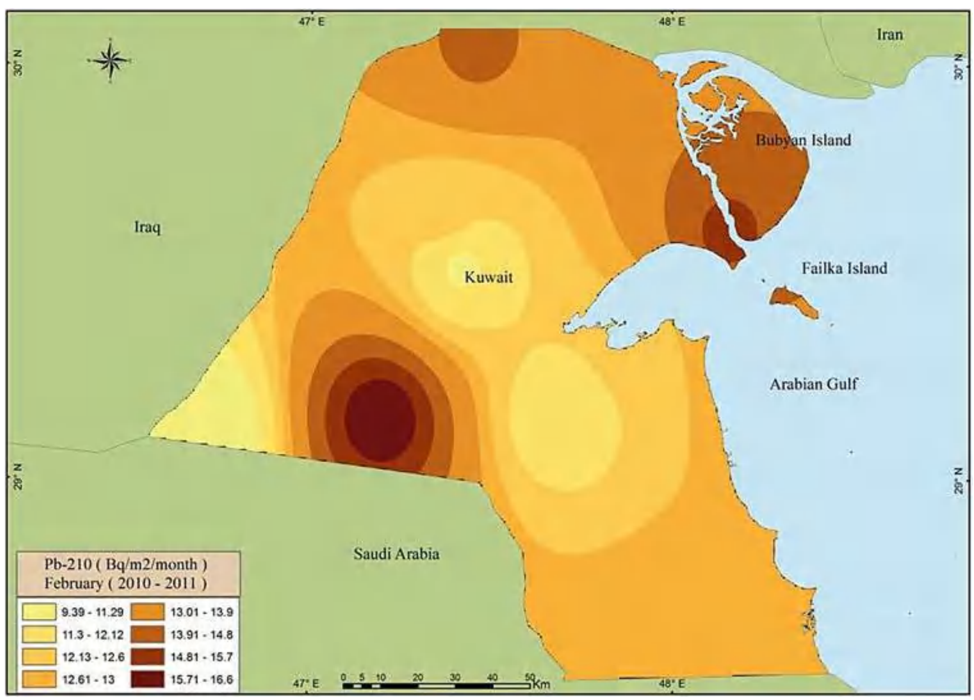


Fig. 6.44 Average deposited rates of ^{210}Pb in February (2010–2011)

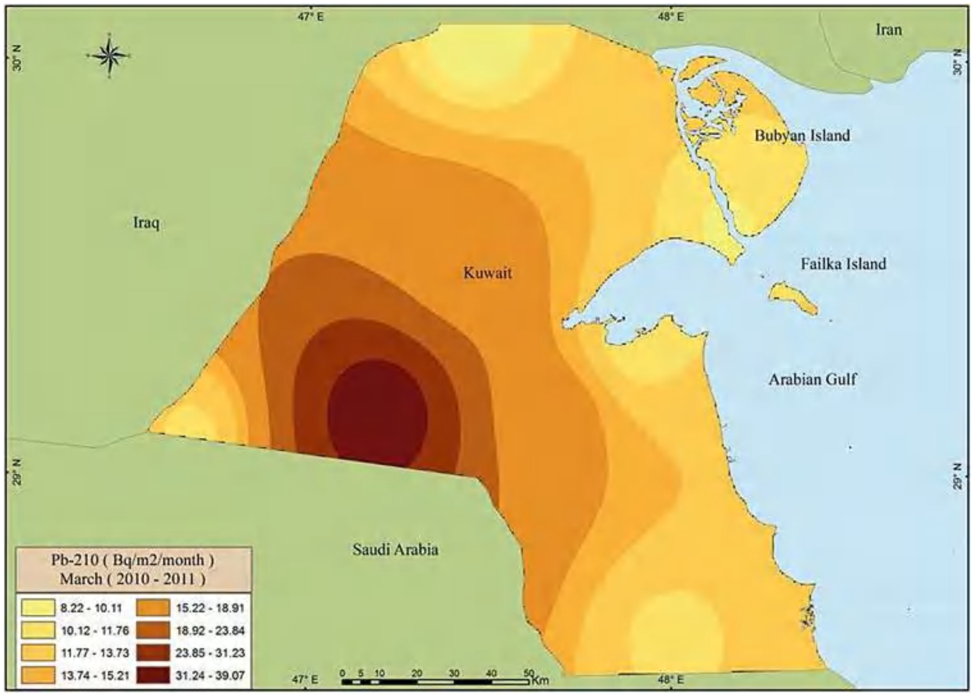


Fig. 6.45 Average deposited rates of ^{210}Pb in March (2010–2011)

with a high wind speed of northeastern, eastern, and south-eastern wind contribution (Fig. 6.46).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Liyah Huwaymilyah	Salmi Sulaybiyah
Dibdibah Ratqah Doha	Subiyah Kabd Bubiyan Island

(continued)

The monthly ^{210}Pb rates deposited in Kuwait during May 2010–2011 ranged from 8.19 to 30.44 Bq m^{-2}, with the

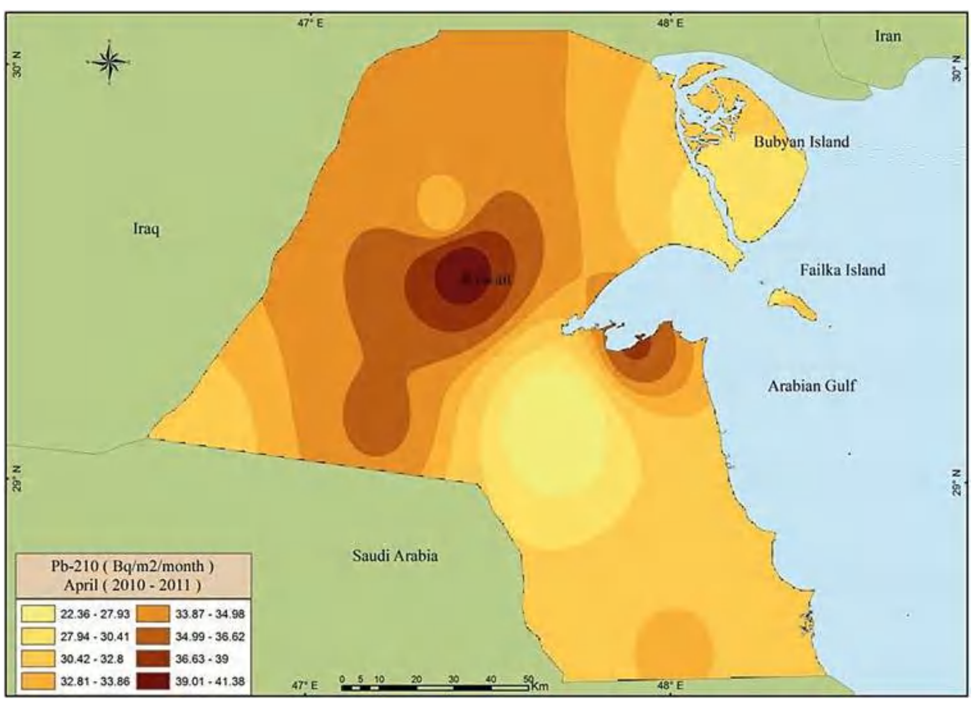


Fig. 6.46 Average deposited rates of ^{210}Pb in April (2010–2011)

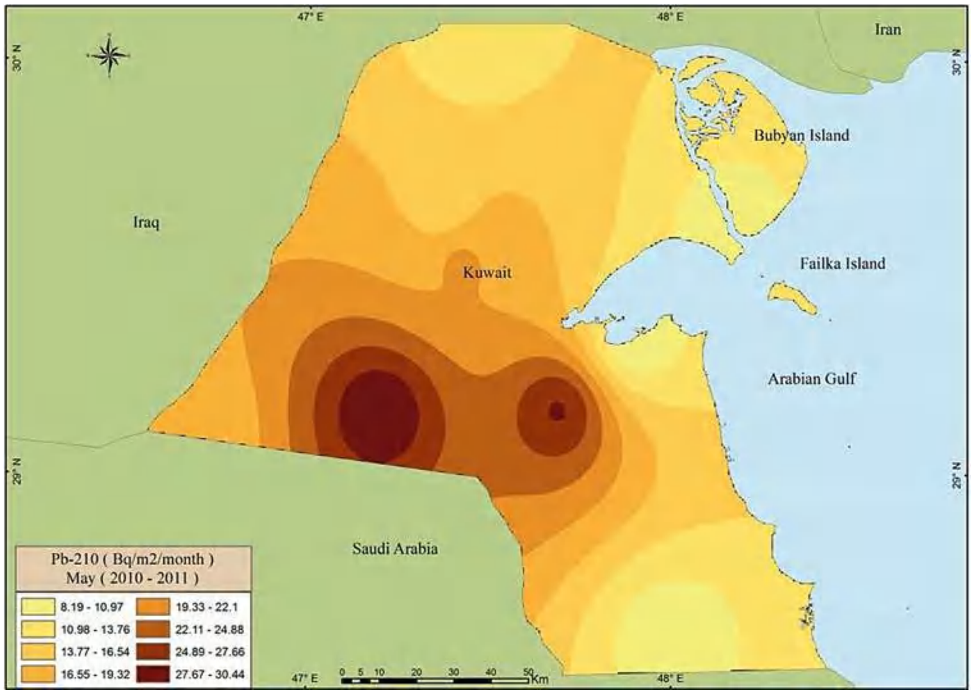


Fig. 6.47 Average deposited rates of ^{210}Pb in May (2010–2011)

maximum in the southeastern and central areas. The lowest deposition fluxes were in the southern and eastern areas. However, the slightly high deposition flux in this month was because of the effect of the exotic that storm hit Kuwait on March 25, 2011 (Fig. 6.47).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Dibdibah Liyah Ubayriq Kabd	Doha Subiyah Ratqah Salmiya Wafra Farms

The monthly ^{210}Pb rates deposited in Kuwait during June 2010–2011 were lower compared with previous months, with a range from 4.17 to 20.2 Bq m^{-2}. The maximum rates were in the southeastern areas and the lowest in the central areas. The predominant wind direction for this month was northwesterly, with no precipitation events (Fig. 6.48).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Dibdibah Liyah Ubayriq Bubiyan Island	Doha Sulaybiyah Ratqah Salmi Wafra Farms

Similar to June, the monthly ^{210}Pb deposited rates in Kuwait during July 2010–2011 were lower when compared with previous months. The range of deposition fluxes varied between 3.09 and 15.48 Bq m^{-2}. The maximum rates were in the northeastern areas and the lowest in the southern and northeastern areas. The predominant wind direction for this month was northwesterly, with no precipitation events or impact wind from other directions (Fig. 6.49).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Dibdibah Liyah Ubayriq Kabd	Doha Subiyah Ratqah Salmiya Bubiyan Island

The monthly ^{210}Pb deposited rates in Kuwait during August 2010–2011 were lower than in June and July, with a range that varied from 2.16 to 9.72 Bq m^{-2}, with the maximum in the northern and southwestern areas, and the lowest within the transect along the northwesterly wind corridor (Fig. 6.50).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Dibdibah Ratqah Ubayriq Bubiyan Island	Doha Sulaybiyah Um Al Madafi’ Salmi Wafra Farms

Similar to the summer months, the monthly ^{210}Pb deposited rates in Kuwait during September 2010–2011 had low rates that ranged from 1.8 to 10.64 Bq m^{-2}, with the

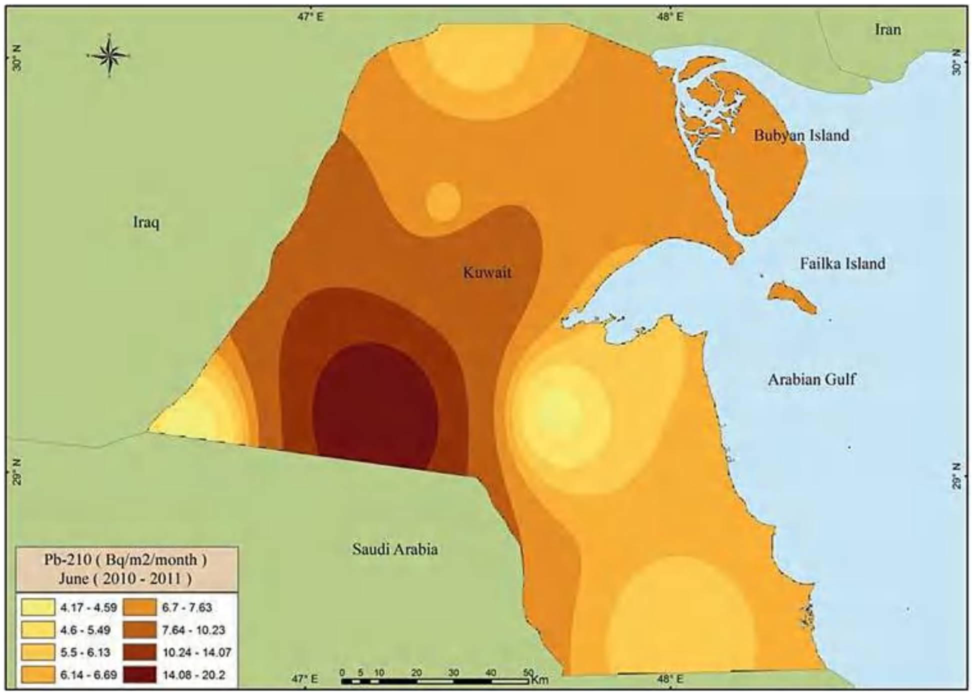


Fig. 6.48 Average deposited rates of ^{210}Pb in June (2010–2011)

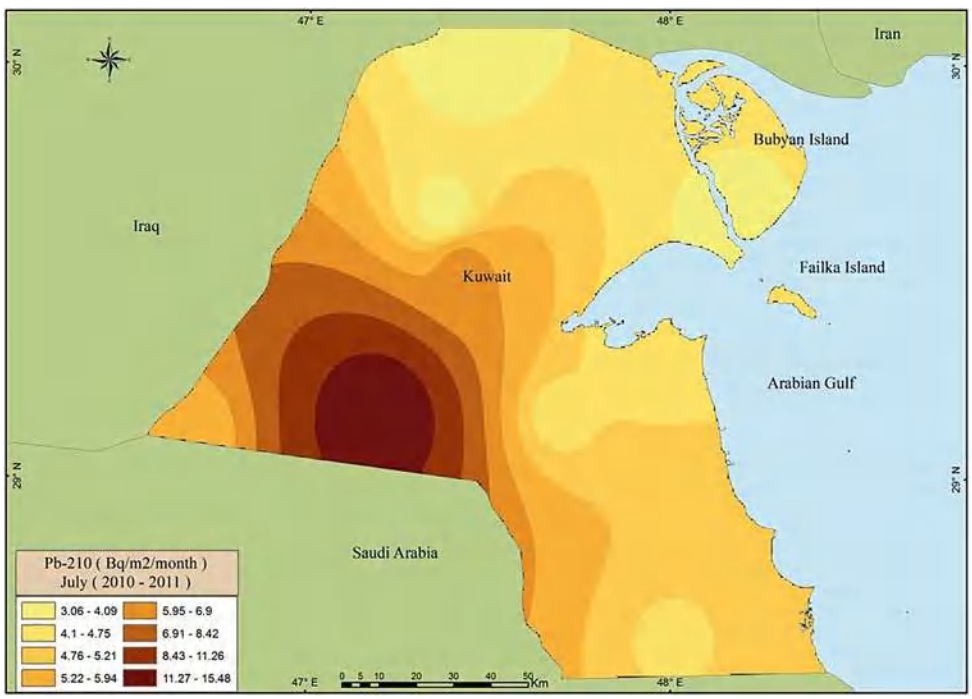


Fig. 6.49 Average deposited rates of ^{210}Pb in July (2010–2011)

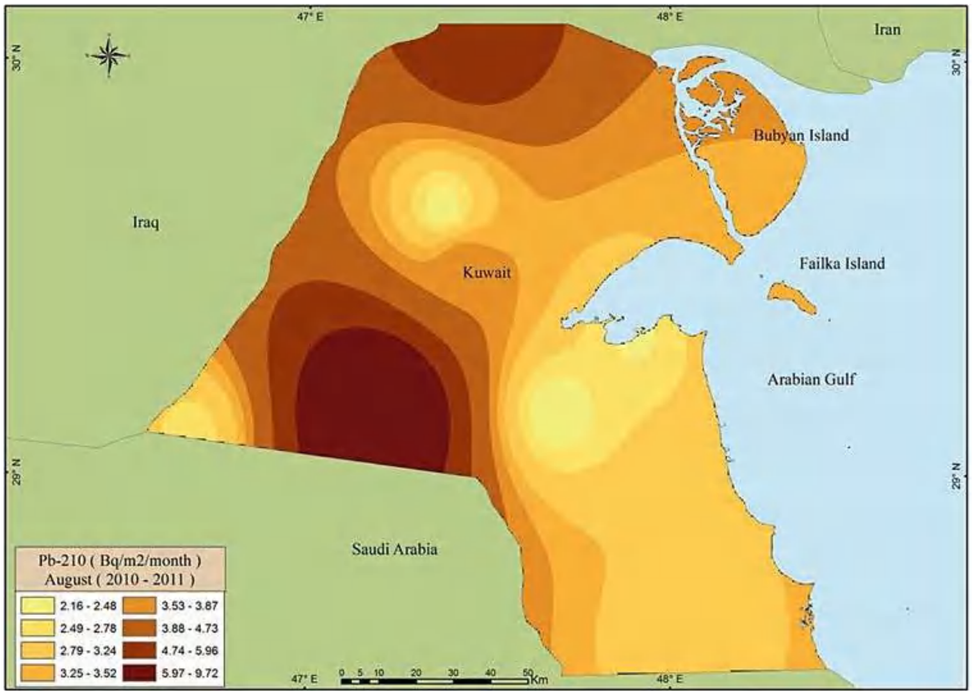


Fig. 6.50 Average deposited rates of ^{210}Pb in August (2010–2011)

maximum in the northwestern areas and the lowest in the southern and southwestern areas. The predominant wind direction in this month was northwesterly, with no contribution from other directions (Fig. 6.51).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Dibdibah Liyah Ubayriq Kabd	Doha Sulaybiyah Failaka Island Salmi Wafra Farms

Similar to the summer months, the monthly ^{210}Pb deposited rates in Kuwait during October 2009–2010 showed low rates, with a range that varied from 2.52 to 8.74 Bq m^{-2}, with the maximum in the southeastern and northern areas and the lowest along the northwesterly wind corridor (Fig. 6.52).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Abdulli Dibdibah Ratqah Ubayriq Shegaya	Doha Sulaybiyah Um Al Madafi' Khiran Wafra Farms

The monthly ^{210}Pb deposited rates in Kuwait during November 2009–2010 were moderate, ranging from 5.25 to 14.2 Bq m^{-2}, with the maximum in the central and southeastern areas and the lowest in the southern areas. The predominant wind direction was northwesterly at a minimum speed (Fig. 6.53).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Huwaymilyah Dibdibah Doha Ubayriq Bubiyan Island	Abdulli Sulaybiyah Ratqah Salmi Wafra Farms

The monthly ^{210}Pb rates deposited in Kuwait during December 2009–2010 were similar to November. The rates varied from 4.74 to 14.06 Bq m^{-2}, with the maximum in the southwestern and central eastern areas. The predominant wind direction was northwesterly, with high speed at times (Fig. 6.54).

Areas with high radionuclide concentration	Areas with low radionuclide concentration
Doha Dibdibah Ratqah Ubayriq Um Al Madafi'	Ratqah Sulaybiyah Salmi Khiran Wafra Farms

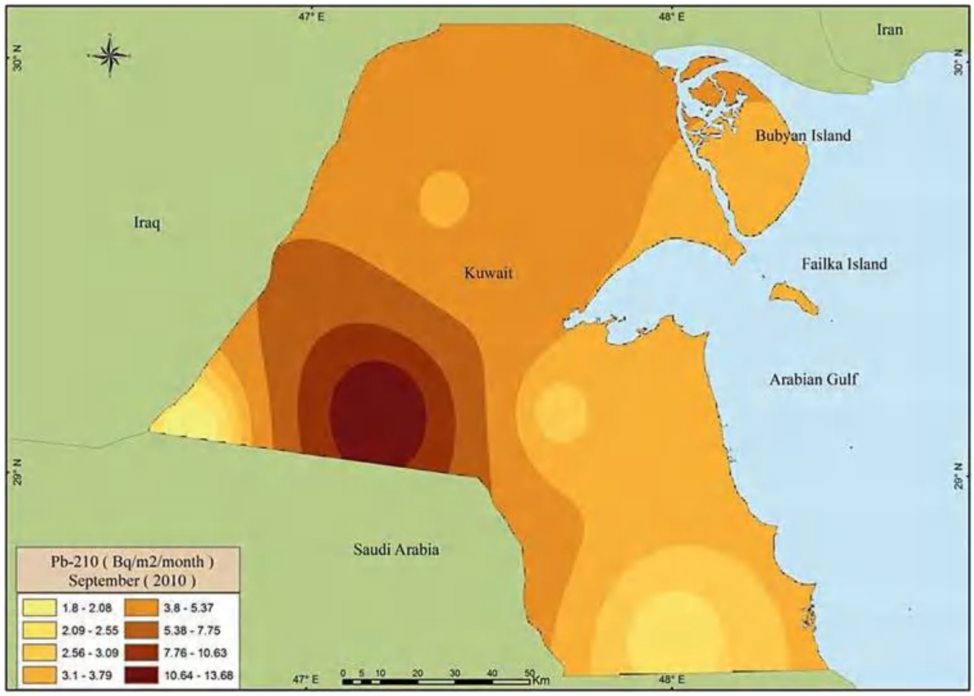


Fig. 6.51 Average deposited rates of ^{210}Pb in September (2010)

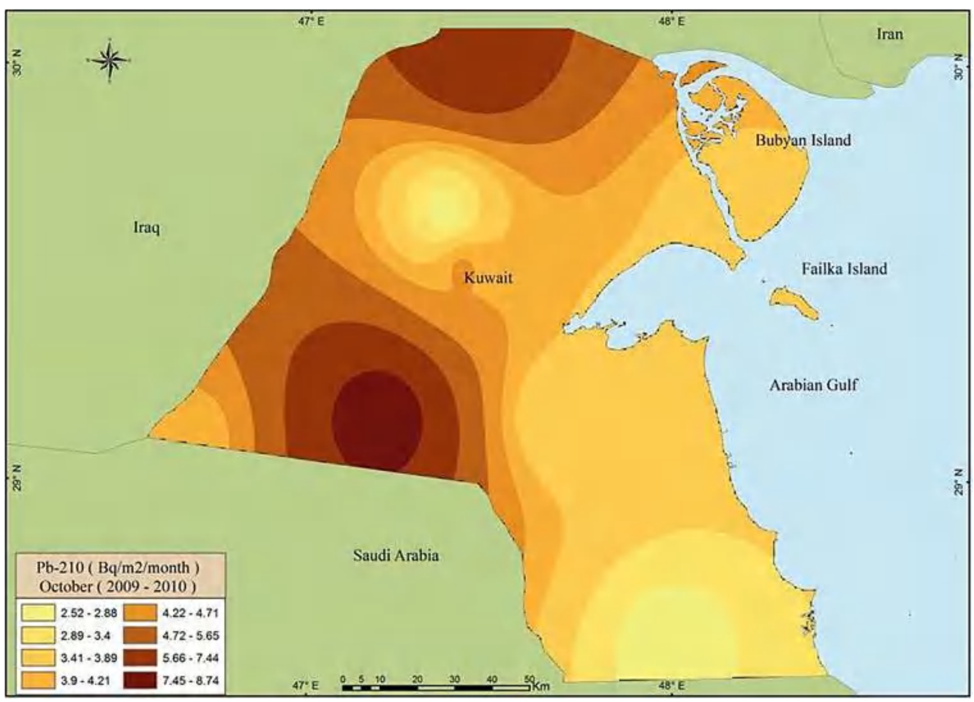


Fig. 6.52 Average deposited rates of ^{210}Pb in October (2009–2010)

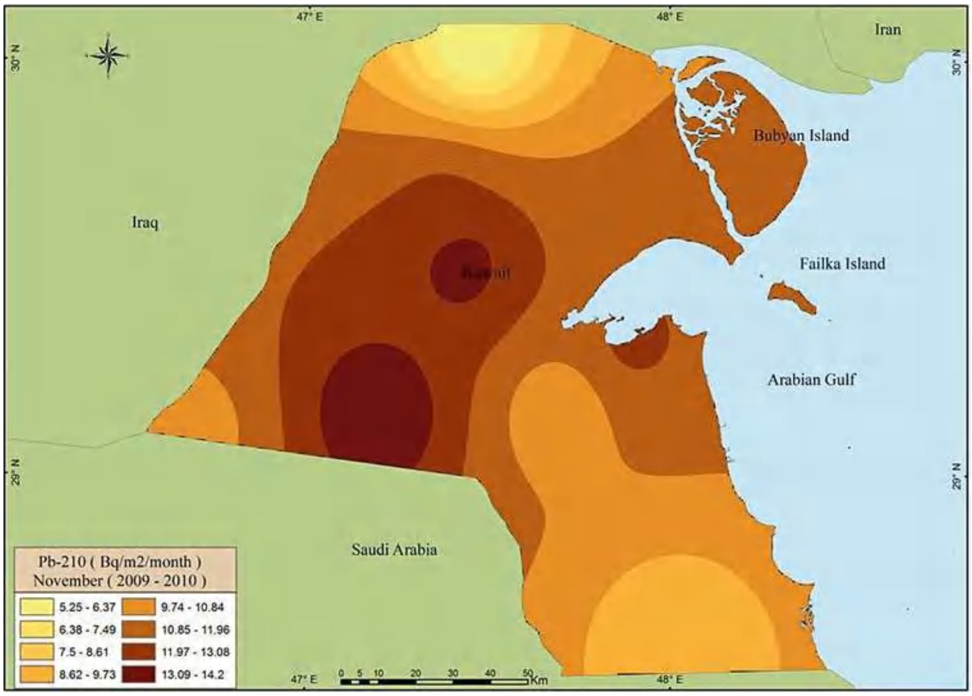


Fig. 6.53 Average deposited rates of ^{210}Pb in November (2009–2010)

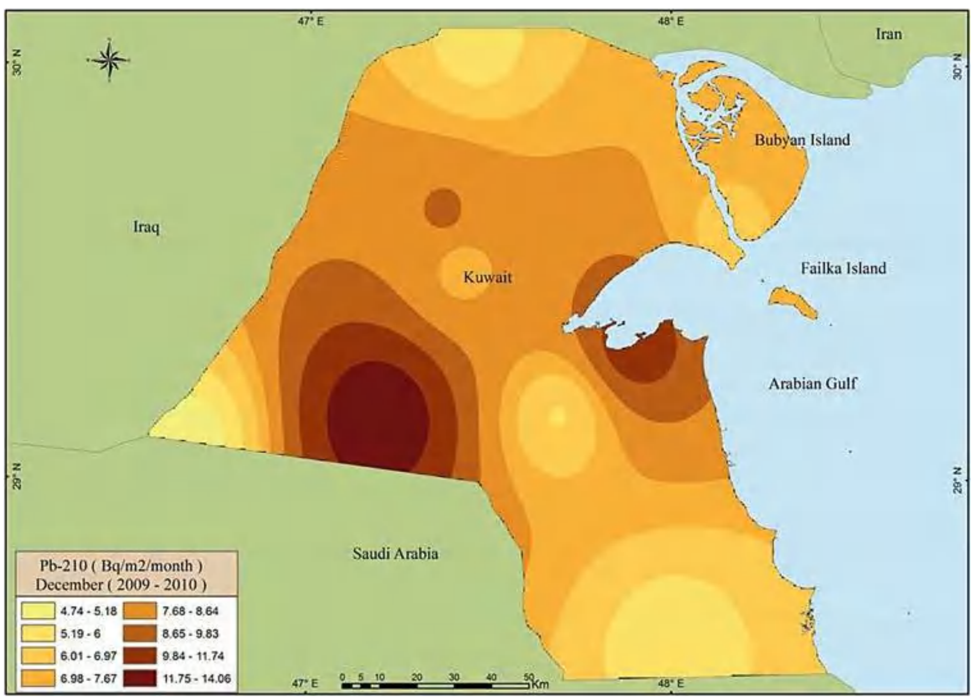


Fig. 6.54 Average deposited rates of ^{210}Pb in December (2009–2010)

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7 Pollen in Dust

Mohamed Ismail Ibrahim, Ali Al-Dousari, and Abeer Hassan Al-Saleh

Abstract

- Twenty-eight pairs of pollen and aeolian dust traps covering the State of Kuwait were used to obtain seasonal pollen counts of the most eight dominant families during 2009–2011 i.e. Chenopodiaceae, Poaceae (Gramineae), Cyperaceae, Leguminosae (Fabaceae), Cyperaceae, Brassicaceae, Malvaceae, Compositae, and Plantaginaceae.
- The sampling site locations were chosen to cover all the geomorphological sectors and native vegetation areas in Kuwait.
- Generally, pollen counts show us a remarkable distinction between the year 2009–2010 and 2010–2011, It is also evident that pollen counts (concentration) vary from season to season. Pollen counts over four seasons for two years (October 2009–August 2011) reveal the presence of two peaks in spring (April–May) and autumn (October–November).
- Map distribution of pollens in each of the dominant plant families in Kuwait is generated according to seasons showing higher and lower concentrations of dust pollen counts.

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Samples Collection and Preparation

Twenty-eight pairs of pollen and eolian dust traps covering the State of Kuwait (Fig. 7.1) were used. The pollen trap is a simple cylindrical container with 40 cm depth and 20 cm radius fixed at 0 cm and 240 cm from the ground level. The traps were designed to capture bouncing and suspended particles from all directions (Fig. 7.1). The sampling site locations were chosen to cover all the geomorphological sectors and native vegetation areas in Kuwait. The samples within the traps were collected on a monthly basis for a period of 23 months. The weight of the collected samples from all the dust traps was measured. Fifty grams of sand (collected from pollen trap at 0 cm from ground level) was weighted from each station and treated as follows:

1. 50 grams of sand was sieved using a 150 µm sieve.
2. 10 grams of the fine fraction ($\leq$ 150 µm) was washed with distilled water to remove the unwanted organic material, which was then dried.
3. The dried fine dust was soaked in diluted HCl (10%) to remove any carbonates present. Occasional agitation with a polypropylene stirring rod allowed the acid to penetrate the entire sample. If the reaction did not stop before several hours had elapsed, the depleted acid was replaced with fresh acid until all reactions ceased. Heating the sample can speed up the reaction, but only low heat should be used (<95°C).
4. The acid was decanted when the residue had settled.
5. The residue was washed three times with distilled water to assure that the residue was in a neutral medium, which can be determined with calibrated litmus paper.
6. 40–60% hydrofluoric acid was used to remove any silicates present. In this step, the samples were put in polypropylene beakers and, using polypropylene rods, the mixture was left for at least 48 h. Sometimes heating in a water bath can occur.

Fig. 7.1 Dust tarp fixed at 240 cm above ground level (left), and pollen traps before and after fixing (right)

7. The residue was washed with distilled water, as described above in step (5).
8. Concentrated hydrochloric acid was added to the residue to remove any fluorides that may have been precipitated in the post HF water washes. After settling, the acid was decanted.
9. The residue was washed with distilled water, as described in step (5).
10. The residue was left in a glass vial to dry.
11. Glycerin jelly was used as a mounting medium for permanent slides.
12. The pellet of jelly was transferred to a slide; the slide was warmed to allow the jelly to melt. The pollen residue was dispersed in the jelly using a needle.
13. The jelly was allowed to cool slightly. A cover glass was placed on the jelly and pressed slightly using a needle.
14. The cover glass was cleaned in direct tap water and then labeled.

Microscopic Identification

Each sample slide was analyzed for pollen particle and spore content. Each identified particle or spore was counted as the prepared slide was traversed on a mechanical stage under the high-power microscope. Then, a pollen diagram and graphical expression of pollen analysis were constructed.

A seasonal pollen diagram and/or map illustrating the pollen distribution in Kuwait was then prepared according to the following seasons:

(a) Fall (October–November 2009 and 2010)
(b) Winter (January–February 2010 and 2011)
(c) Spring (April–May 2010 and 2011)
(d) Summer (July–August 2010 and 2011).

Climate and Vegetation

The climate of Kuwait is characterized by very hot, dry summers and cool to mild rainy winters. The rainfall pattern follows that of arid environments, being erratic and inconsistent, and showing great temporal and spatial fluctuations (Ahmed and Al-Dousari 2013). Records reveal that the average seasonal rainfall (October to April) total is 115 mm, with wide fluctuations between 29 mm and 262.7 mm. Rainfall usually occurs between November and May, while occasional showers may fall during May (Al-Dousari et al. 2020a). The mean temperature reaches its maximum during July–August (about 44°C) and its minimum during January (about 8 °C). Mean values of RH range between 90% in January and 31% in June, while the mean number of dusty days is 23 during July and nine during December (Al-Dousari et al. 2020b).

Kuwait's vegetation comprises eight units, which are described by Omar (2000) as follows:

1. HALOXYLETUM (Chenopodiaceae): It covers about 23% of the total area of Kuwait. It is dominated by the species *Haloxylon salicornicum*, a low shrub that grows

up to 60 cm in height. The community type covers large areas in the northern and western parts of Kuwait.

2. RHANTERIETUM (Compositae): The total area covered by the community is about 7% of Kuwait. It is dominated by the species *Rhanterium epapposum* in association with *Convolvulus oxyphyllus, Moltkiopsis ciliate, Helianthemum lippi, Centropodia forsskalii,* and *Stipagrostis plumosa.* It occurs in small patches in the northern, central, and southern parts of Kuwait.
3. CYPERETUM (Cyperaceae): It is one of the most extensive vegetation units in Kuwait, covering approximately 26% of the country. The sedge *Cyperus conglomeratus* dominates it.
4. STIPAGROSTIETUM (Gramineae/Poaceae): It is dominated by *Stipagrostis plumosa*. It extends in the west and southwest of Kuwait, with few clusters in the north and northwest. The Stipagrostietum map unit covers 39% of Kuwait.
5. ZYGOPHYLLETUM (Zygophyllaceae): This type is dominated by *Zygophyllum qatarense*, which is a medium-sized shrub commonly found in coastal areas and depressions. The total distribution of the community is 1% of the total vegetation.
6. CENTROPODIETUM (Gramineae/Poaceae): This map unit is dominated by the species *Centropodia forsskalii*, a perennial grass that has recently become abundant in the southwest of Kuwait. The *Centropodietum* map unit covers approximately 1% of Kuwait.
7. PANICETUM (Gramineae/Poaceae): It is dominated by *Panicum turgidum*, a perennial desert grass forming tangled bunches up to 1 m tall. The distribution of the plant is very limited: estimated at < 1% of Kuwait.
8. HALLOPHYLETUM (Tamaricaceae): This map unit is dominated by many halophytic plant communities, such as *Tamarix aucheriana*, *Nitraria Retusa*, *Halocnemum strobilaceum*, and *Seidlitzia rosmarinus*. It is found in the northern and southern coastal areas of Kuwait. The total area is about 1.5% of Kuwait.

Results

Total Pollen Count

Generally, pollen counts reveal a remarkable distinction between the year 2009–2010 and 2010–2011: the pollen particle concentration in 2009–2010 was higher in percentage than that of 2010–2011 (Figs. 7.4, 7.5). It is evident also that pollen counts (concentration) vary from season to season. Pollen counts over four seasons for two years (October 2009–August 2011) reveal the presence of two peaks in spring (April–May) and fall (October–November). The first peak is higher and is due to the greater number of pollen particle species that flower during the spring season, such as *Chenopodiaceae, Poaceae (Gramineae), Cyperaceae, Leguminosae (Fabaceae),* and *Plantaginaceae*. The second peak in fall (October–November) is lower and is characterized by the abundance of *Chenopodiaceae* and *Leguminosae* (Fig. 7.3).

On the other hand, two troughs are apparent during summer (July–August) and winter (January–February) due to summer drought, dust storms, and winter wind and rainfall. The summer lows are characterized by higher counts than the winter lows. In summer and fall, *Chenopodiaceae* dominates, followed by *Leguminosae* (Fig. 7.2).

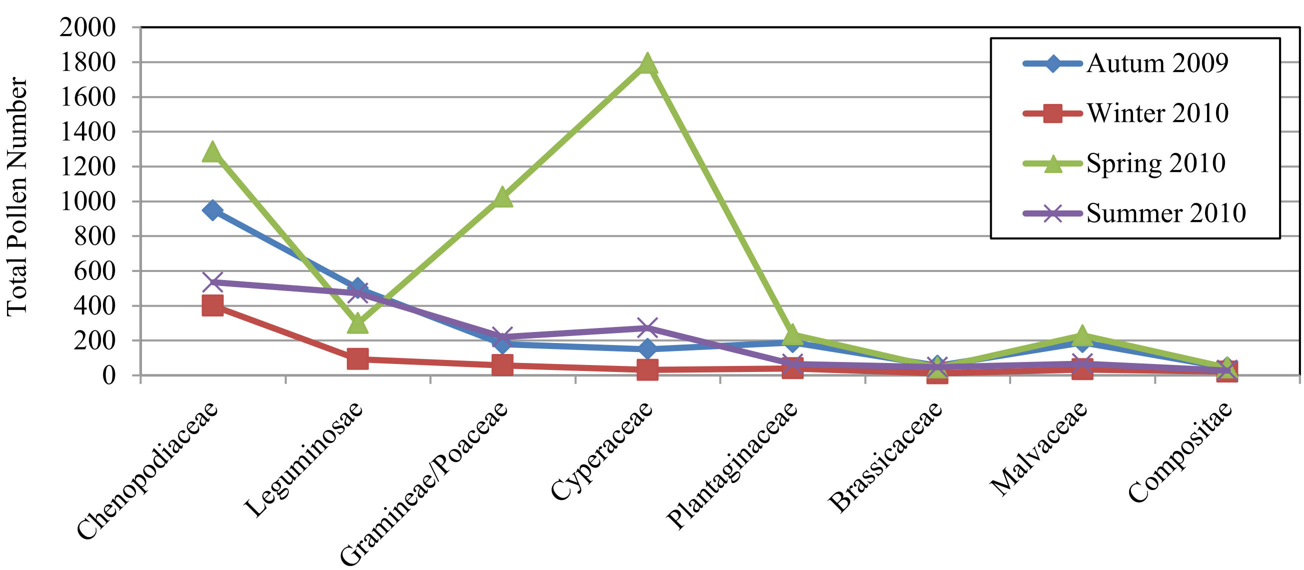

Fig. 7.2 Seasonal pollen counts of the most dominant families during 2009–2010

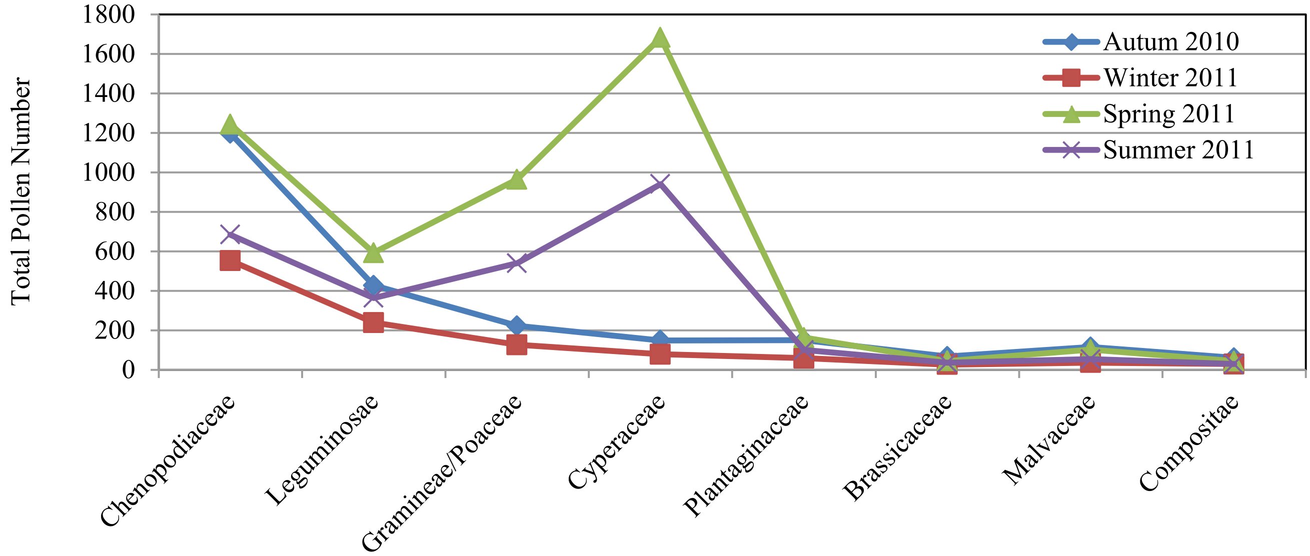

Fig. 7.3 Seasonal pollen counts of the most dominant families during 2010–2011

Among the 28 sites, the highest counts over the two years of study were recorded at sites 13, 15, 14, and 7, in descending order, especially in fall and spring (Fig. 7.4).

Chenopodiaceae and *Leguminosae* together comprise over 70% of the total pollen during fall.

Local flora is the main source of the pollen load, and the concentration depends on the amount of vegetation around each station, except for a very low percentage (2–3%) of *Pinaceae* pollen recorded in the north and northwest of Kuwait, which could be interpreted as being transported by the northwesterly wind. *Chenopodiaceae* had a high percentage (90%) during fall 2009. The spring peaks are higher because of the greater number of *Cyperaceae* and *Gramineae*. Generally, the pollen count for the period 2009–2010 is higher than 2010–2011.

Twenty-eight pairs of pollen and eolian dust traps were used throughout Kuwait. The pollen trap distribution was based on two parameters:

1. The dominant native desert plant dispersal in Kuwait and the surrounding region were selected in accordance with vegetation maps prepared by Dickson (1955), Kernick (1966), Ergun (1969), Macksad (1969), Halwagy and Halwagy (1974), and Omar (2000). These plants are *Cyperus conglomeratus, Haloxylon salicornicum, Rhanterium epapposum, Astragalus spinosus, Lycium shawii, Citrullus colocynthis, Panicum turgidum, Calligonum polygonoides*, *Nitraria retusa, Tamarix aucheriana, Halocnemum strobilaceum, Salicornia europaea*, *Heliotropium bacciferum, Arnebia decumbens,* and *Convolvulus oxyphyllus*.
2. The geomorphology of the area, because there is a positive relationship between the types of native plants present, in which most of the plants are present within drainage systems such as water, wadis, playas, and sabkhas.

   According to the above-mentioned parameters, the pollen traps were selected.

Mohamed et al. (1983) found a highly significant correlation between the concentration of *Cyperus, Plantago,* and *Brassicaceae* pollen. *Brassicaceae* is a large family of plants with four-petaled flowers. For spring 2011, the pollen distribution and abundance indicate the same trend as in spring 2010, with an abundance of *Cyperaceae* (33.7%) followed by *Chenopodiaceae* (24.9%), *Gramineae* (19.3%), *Leguminosae* (12%), *Plantaginaceae* (3.2%), *Malvaceae* (1.9%), *Ephedraceae* (1.2%), and *Brassicaceae* (1.1%). The highest of all pollen noted in Kuwait during springtime was *Brassicaceae*, which appears mostly around farms and cultivated urban areas, such as in Wafra Farms, Liyah, and Qurain (Fig. 7.5).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Qurain	Abdulli
Liyah	Ratqah
Salmiya	Salmi
Kabd	Burqan
Wafra Farms	Subiyah

Al-Dousari et al. (2018) found a highly significant correlation between the concentration of *Cyperus, Plantago,* and *Brassicaceae* pollen. *Brassicaceae* is a large family of plants with four-petaled flowers. For spring 2011, the pollen distribution and abundance indicate the same trend as in

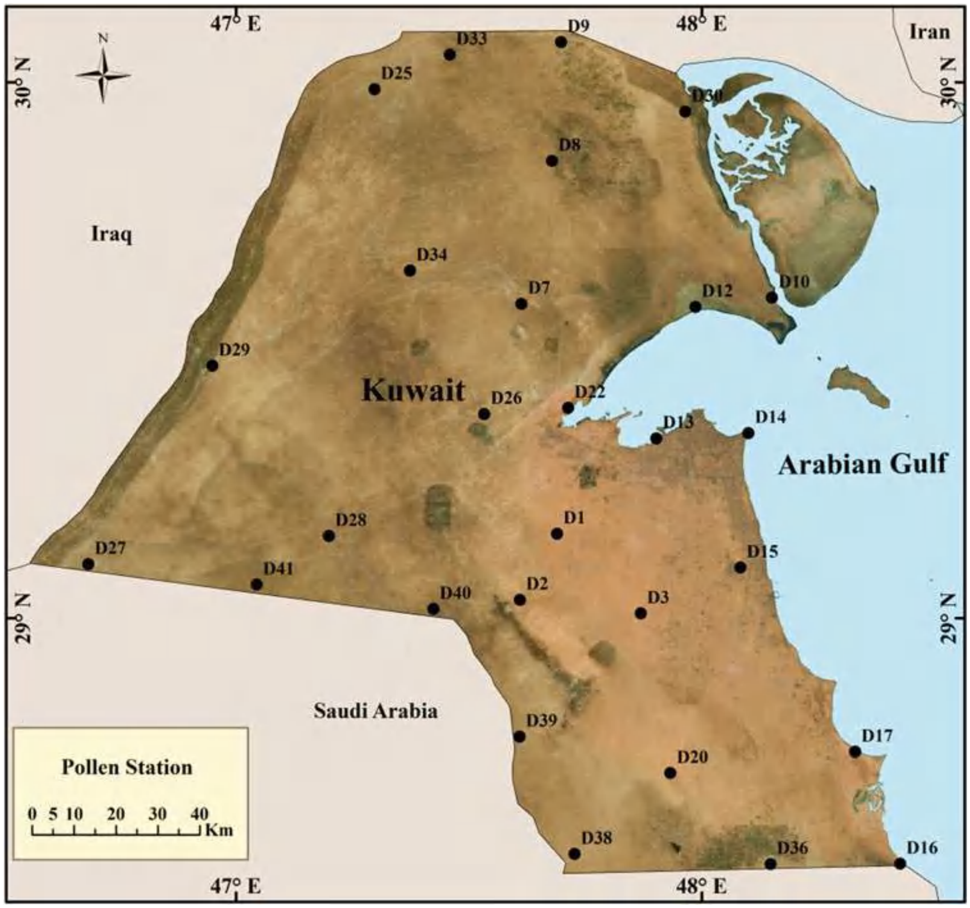

Fig. 7.4 Kuwait image showing the location of the pollen and dust sampling sites

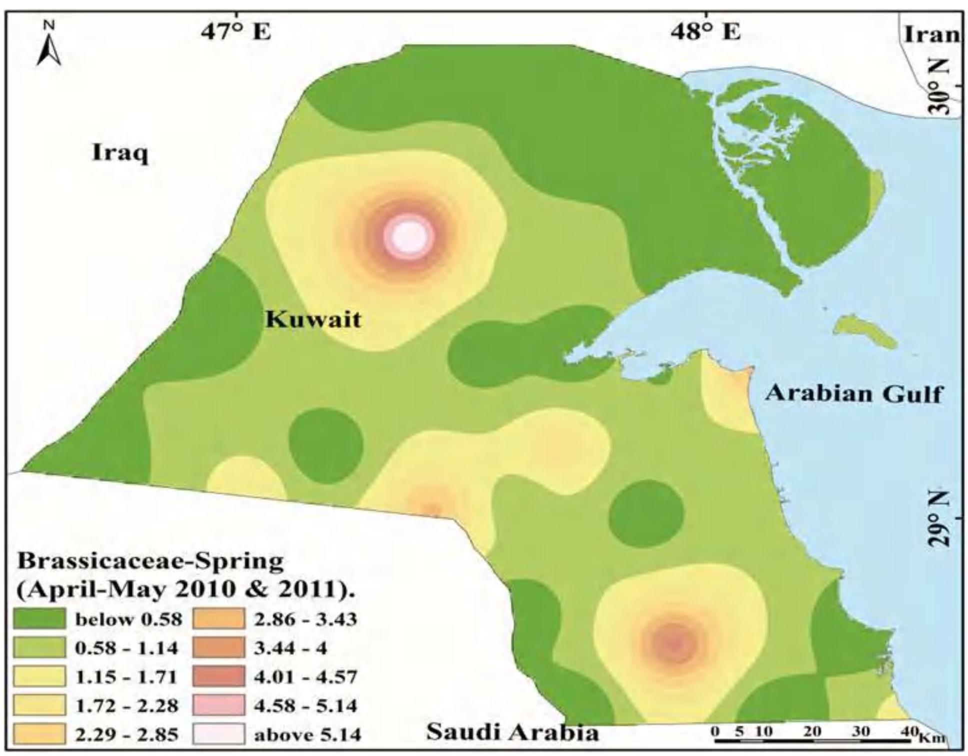

Fig. 7.5 Average percentages of *Brassicaceae* pollen in dust. Spring (April–May 2010 and 2011)

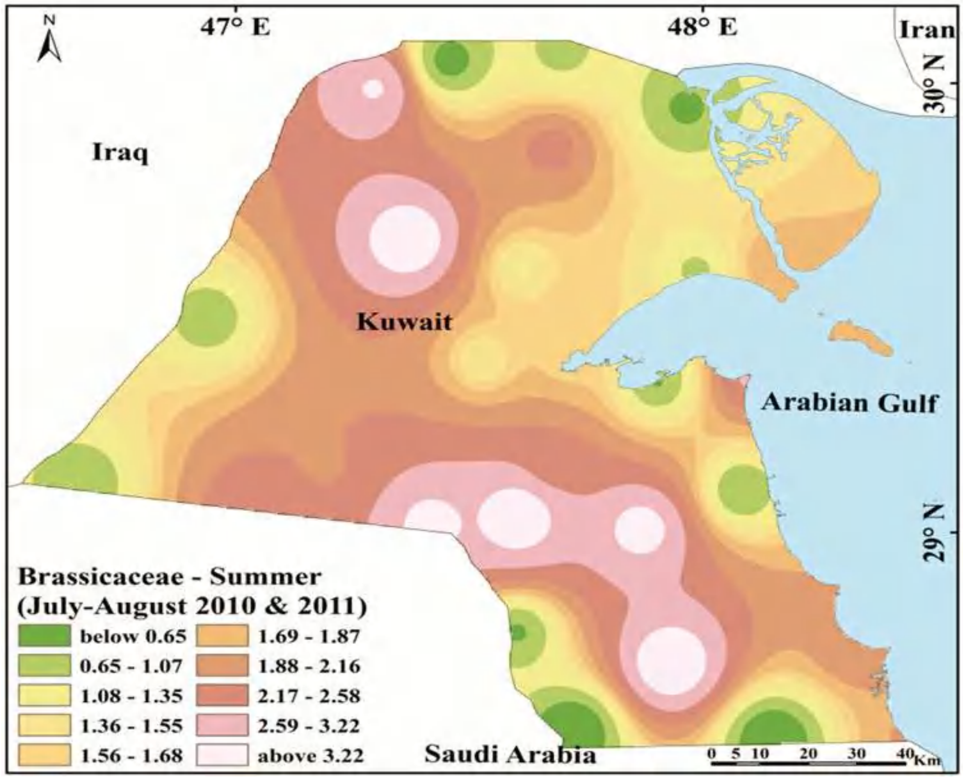

Fig. 7.6 Average percentages of *Brassicaceae* pollen in dust. Summer (July–August 2010 and 2011)

spring 2010, with an abundance of *Cyperaceae* (33.7%) followed by *Chenopodiaceae* (24.9%), *Gramineae* (19.3%), *Leguminosae* (12%), *Plantaginaceae* (3.2%), *Malvaceae* (1.9%), *Ephedraceae* (1.2%), and *Brassicaceae* (1.1%). The highest of all pollen noted in Kuwait during springtime was *Brassicaceae*, which appears mostly in farms and other cultivated urban areas, such as in Kabd, Liyah, and Qurain. The distribution of *Brassicaceae* is similar to the distribution of other pollen during summer (Fig. 7.6).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Qurain Burqan Jreshan Liyah Kabd	Um Niqa Ratqah Ubayriq Salmi Wafra Farms

The highest percentages of *Brassicaceae* pollen were noted during fall. The pollen appeared mostly around farms and cultivated urban areas, such as in Wafra Farms, Salmiya, and Qurain. The distribution of *Brassicaceae* is completely different from the distribution of other pollen during fall. The high distribution takes the form of a corridor that extends from Huwaymilyah to northern Kuwait Bay. There are two major wind corridors in Kuwait, one showing higher concentrations up to 48% in Huwaymilyah and the other with very low concentrations in Um Niqa. This result indicates that *Brassicaceae's* dominant source area is the Western Desert of Iraq, and it is rarely found in the Mesopotamian Floodplain upwind of the Um Niqa wind corridor (Fig. 7.7).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Um Al Madafi' Huwaymilyah Subiyah Ratqah Qurain	Ratqah Abdulli Um Niqa Salmi Burqan

Chenopodiaceae covers about 23% of the total area of Kuwait. The most dominant pollen family reached its maximum abundance (90%) during fall 2009. The highest pollen concentrations were recorded in fall 2009 around Kuwait City, and in the southeast, northwest, and northeast of Kuwait; whereas, the lowest concentrations were recorded during winter 2010 and 2011. The most common genera are *Bienertia, Brassia, Chenopodium, Cornulaca, Halocnemum, Hammada, Salsola, Seidlitzia,* and *Schanginia*. *Haloxylon salicornicum* is a low dominant shrub that grows up to 60 cm in height. The community type covers large areas in the

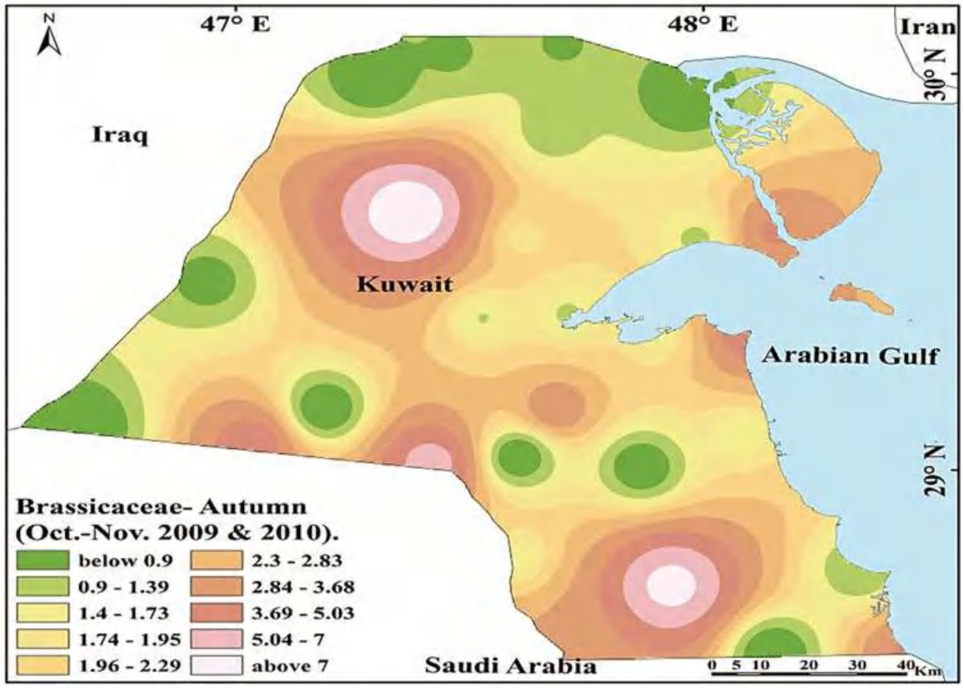

Fig. 7.7 Average percentages of *Brassicaceae* pollen in dust. Autumn (October–November 2009 and 2010)

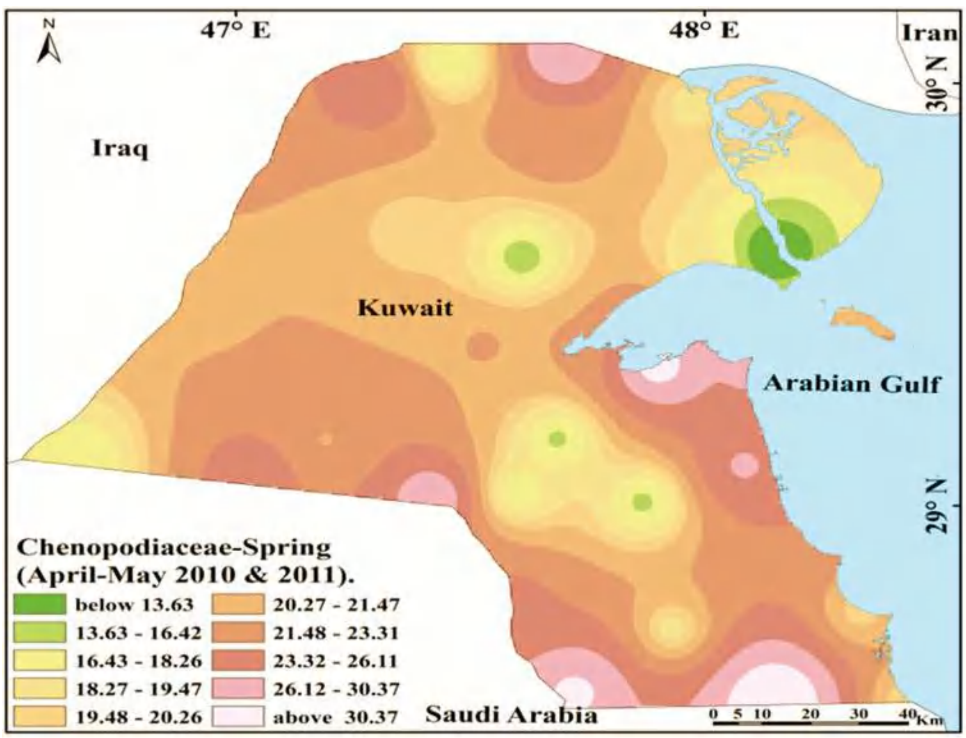

Fig. 7.8 Average percentages of *Chenopodiaceae* pollen in dust. Spring (April–May 2010 and 2011)

northern and western parts of Kuwait. The average counts of *Chenopodiaceae* pollen in the dust during spring (April–May 2010 & 2011) reveal a similar distribution density to that of *Cyperaceae* pollen, which indicates a close distribution between the two dominant native plants, namely *Haloxylon salicornicum* from the *Chenopodiaceae* family and *Cyperus conglomeratus* from the *Cyperaceae* vegetation family. *Haloxylon salicornicum* flourished from October until December. *Haloxylon salicornicum* pollen is heavy when compared with other native plants, and its pollen largely comes from local and nearby regional sources. Therefore, *Haloxylon salicornicum* pollen's maximum counts were in areas such as Shuaiba, Subiyah, Liyah, and Abdulli. In spring 2010 and 2011, the most abundant pollen families belonged to *Cyperaceae* (33.6% and 33.7%, respectively) and *Chenopodiaceae* (24% and 24.9%, respectively) (Fig. 7.8).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Abdulli Khur Fawaris Wafra Farms Shuaiba Shuwaikh	Ratqah Um Eish Subiyah Sulaybiyah Salmi

The average counts of the *Chenopodiaceae* pollen in the dust during summer (July–August 2010 and 2011) show similar distribution density to that in spring with *Cyperaceae* pollen. Summer had the lowest counts for most of the native plants' pollen. Mutla had the highest counts, as it is surrounded by preserved and protected areas that are densely vegetated by *Haloxylon salicornicum*. *Haloxylon salicornicum* pollen had the maximum counts in areas such as Shuaiba, Shuwaikh, Wafra Farm, and Um Rimam. Most of the northern borders with Iraq, the southern areas of Kuwait, and the areas around Kuwait Bay show no counts of *Chenopodiaceae*. *Chenopodiaceae* and *Leguminosae* together comprise over 70% of the total pollen during fall. In summer 2010 and 2011, the highest counts were from *Chenopodiaceae* (32.8% and 33% respectively) (Fig. 7.9).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Abdulli Khur Fawaris Wafra Farm Shuaiba Shuwaikh	Ratqah Liyah Subiyah Qurain Salmi

The total area covered by the pollen community is about 7% of Kuwait. The polllen is dominated by the species *Rhanterium epapposum* in association with *Convolvulus oxyphyllus, Moltkiopsis ciliata, Helianthemum lippi, Centropodia forsskalii,* and *Stipagrostis plumosa*. It occurs in small patches in the northern, central, and southern parts of Kuwait. The average percentages of the composite pollen in dust during spring (April–May 2010 and 2011) are the lowest distribution within most areas in Kuwait. This finding is a good indication of two important notes:

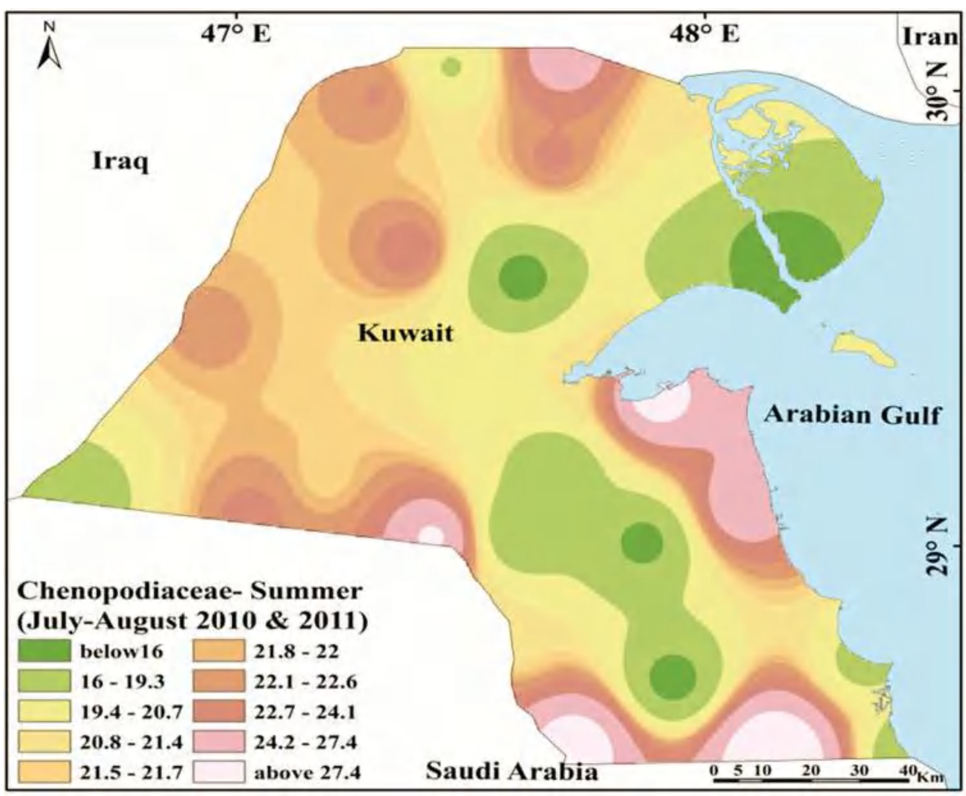

Fig. 7.9 Average percentages of *Chenopodiaceae* pollen in dust. Summer (July–August 2010 and 2011)

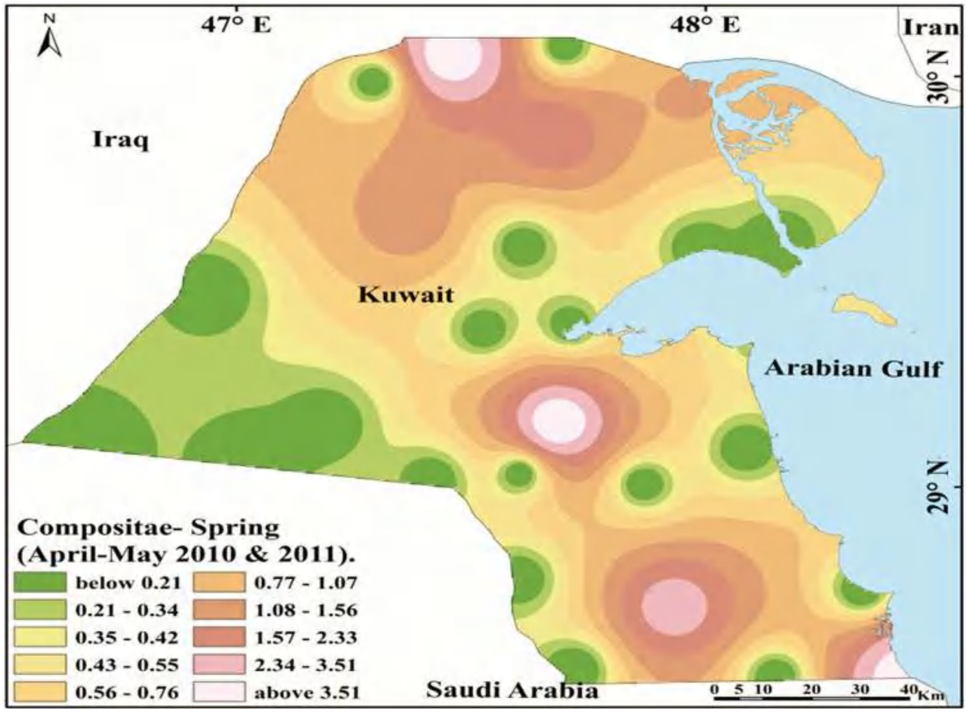

Fig. 7.10 Average percentages of *Compositae* pollen in dust. Spring (April–May 2010 and 2011)

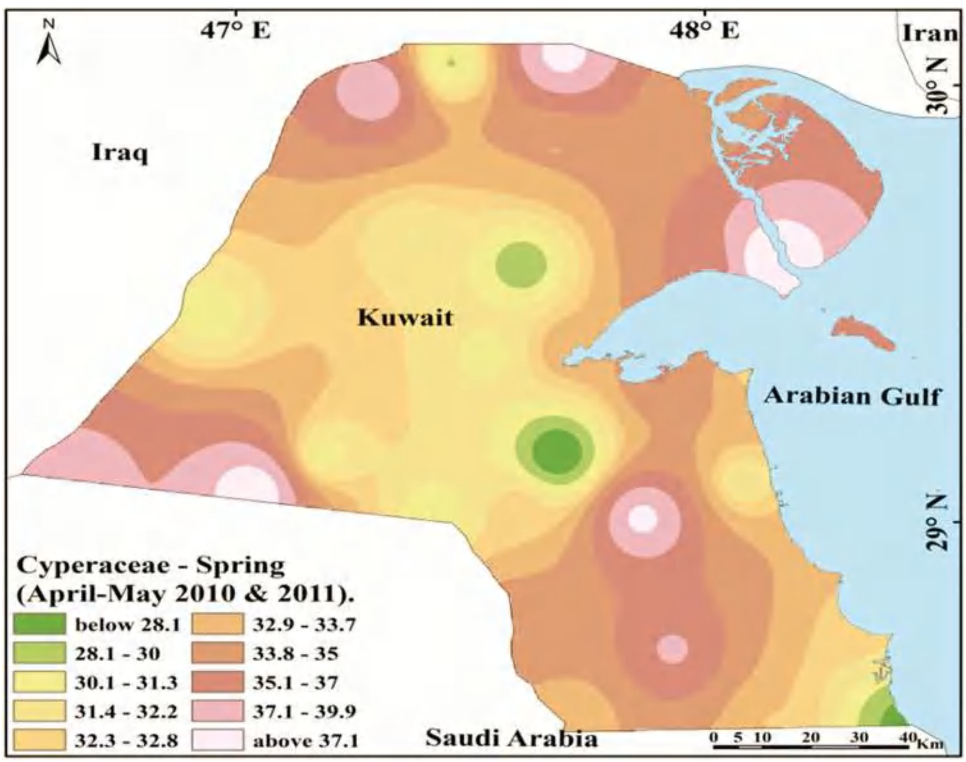

Fig. 7.11 Average percentages of *Cyperaceae* pollen in dust. Spring (April–May 2010 and 2011)

1. The deterioration of the *Rhanteium epapposum* native plant in Kuwait.
2. Dust storm trajectories from the east play a major role in transporting *Rhanteium* pollen from regional sources; there are high counts present in Ratqah, Sulaybiyah, and Burqan (Fig. 7.10).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Ratqah Sulaybiyah Burqan Khiran Um Al- Madafi'	Ratqah Huwaymilyah Um Niqa Jal Al Zur Khiran

Cyperaceae pollen in dust predominantly originates from *Cyperus conglomeratus,* a native plant species in the region. It is one of the most extensive vegetation units in Kuwait, covering approximately 26% of the country. In spring 2010 and 2011, the abundant pollen families belonged to *Cyperaceae* (33.6% and 33.7%, respectively). *Cyperus conglomeratus* flourished in two major times:

1. November–February
2. May–July

The plant is found within mobile sand corridors and away from the preserved areas with dense vegetation. The dense pollen of *Cyperus conglomeratus* appears during wintertime as there are other, more palatable plant species for grazing animals. Therefore, *Cyperus conglomeratus* pollen's maximum counts were in areas such as Subiyah, Dibdibah, and Abdulli. The maximum counts of *Cyperus conglomeratus* in Salmiya could have originated from regional sources from dust storm trajectories that come from the coast (Fig. 7.11).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Abdulli Dibdibah Subiyah Burqan Qurain	Ratqah Um Eish Sulaybiyah Liyah Khiran

Cyperus conglomeratus flourished in summertime in May–July. The low counts for pollen of *Cyperus conglomeratus* during summer are evident as there are no other palatable plant species for grazing animals. Therefore, *Cyperus conglomeratus* is severely grazed by grazing animals (goats, sheep and camels), and this is reflected in the pollen counts, which were much lower than in winter. The maximum counts were in the same areas during winter, such as Subiyah, Um Qudayr, and Abdulli, which might indicate that *Cyperus conglomeratus* pollen is heavy compared with other native plant pollen and largely comes from local and nearby regional sources.

In summer 2010, the highest counts were from *Chenopodiaceae* (32.8%), followed by *Leguminosae* (23.2%), *Cyperaceae* (18.7%), and *Gramineae* (11.5%). In

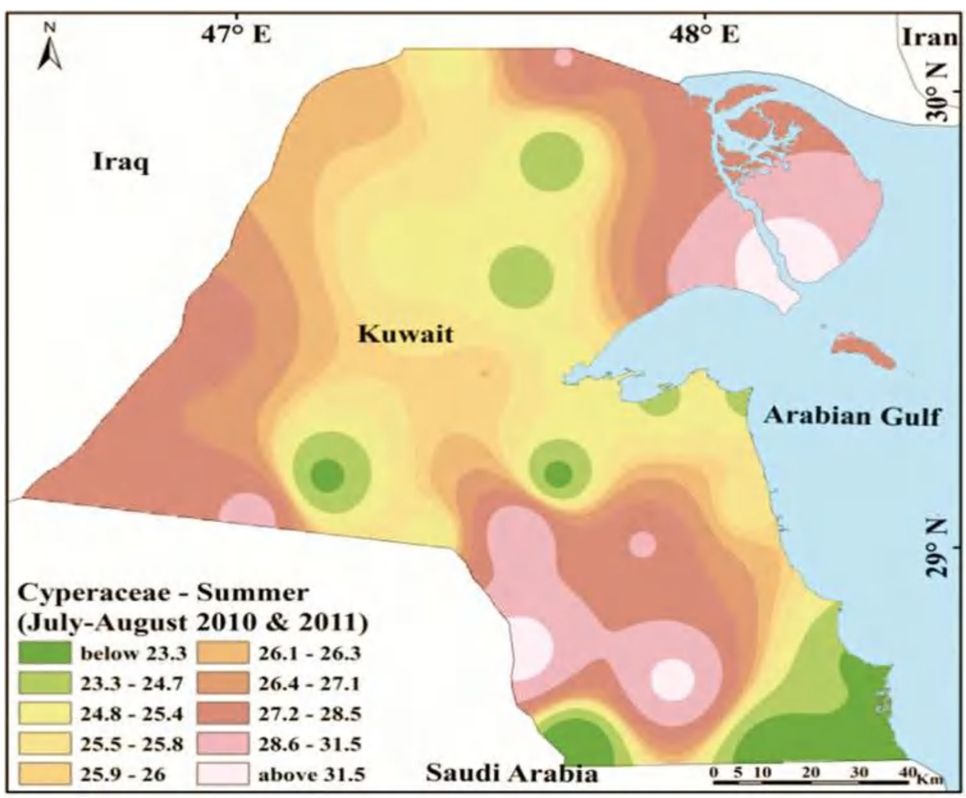

Fig. 7.12 Average percentages of *Cyperaceae* pollen in dust. Summer (July–August 2010 and 2011)

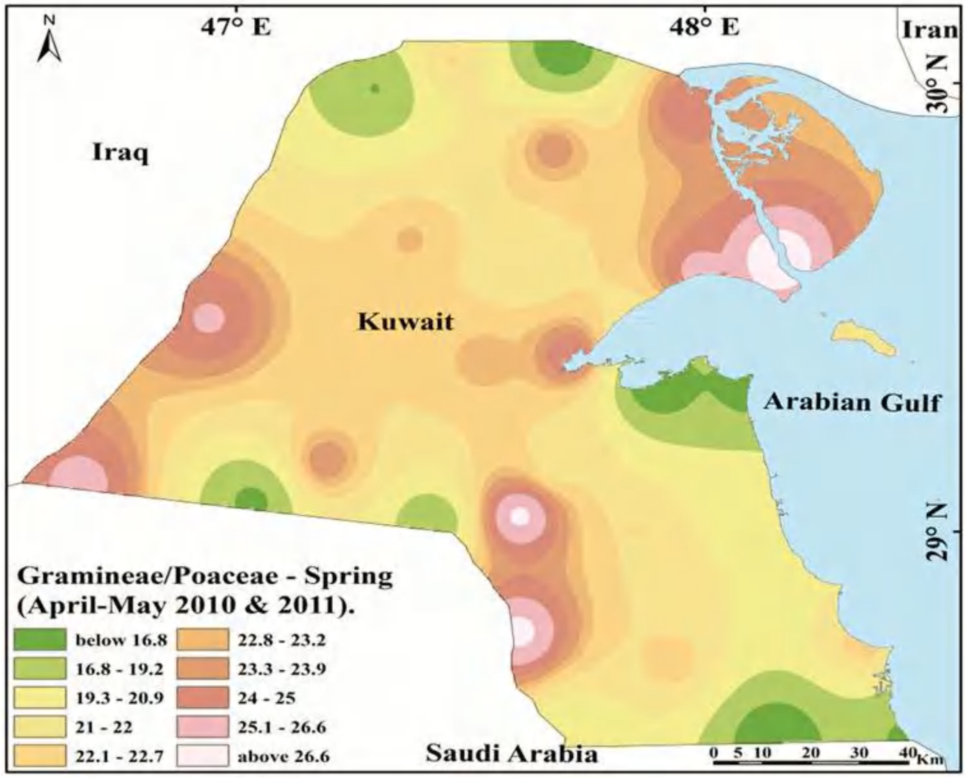

Fig. 7.13 Average percentages of *Gramineae/Poaceae* pollen in dust. Spring (April–May 2010 and 2011)

summer 2011, a similar tendency is apparent, with nearly the same dominance percentage (*Chenopodiaceae*, 33%; *Leguminosae*, 24%; and *Cyperaceae*, 19.4%) (Fig. 7.12).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Abdulli Qurain Subiyah Salmi Um Qudayr	Khur Fawaris Dibdibah Um Eish Salmiya Khiran

Gramineae/Poaceae is dominated in Kuwait by *Stipagrostis* species, such as *plumosa*, *obtusa*, *drarii,* and *ciliata*. It extends to the west and southwest of Kuwait, with a few clusters to the north and northwest. The *Stipagrostietum* map unit covers 39% of Kuwait, including huge areas in the desert environment, and presents densely in dust in areas such as Kabd, Liyah, Subiyah, and Um Qudayr, reaching up to 26.6 counts during spring. The *Stipagrostis* species flourishes from March until May. In spring 2010, the abundant pollen families belonged to *Cyperaceae* (33.6%), followed by *Chenopodiaceae* (24%), and *Gramineae* (19.6%). The same was observed in spring 2011 with *Gramineae* (19.3%) (Fig. 7.13).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Kabd Um Qudayr Subiyah Ubayriq Salmi	Ratqah Huwaymilyah Salmiya Dibdibah Khiran

Gramineae/Poaceae is dominated in Kuwait by the *Stipagrostis* species, which are dominant from March to May. The *Stipagrostis* species during summer reached the maximum counts and were present only in preserved areas such as the border areas, Liyah, and Jal Al Zur, all of which are preserved areas. The maximum and minimum counts of *Gramineae/Poaceae* distribution were similar in spring, summer, and winter, the only difference being in the numbers of detection, as it was the highest in winter and spring but the lowest in summer. In summer 2010, the highest counts were for families of *Chenopodiaceae* (32.8%), followed by *Leguminosae* (23.2%), *Cyperaceae* (18.7%), and

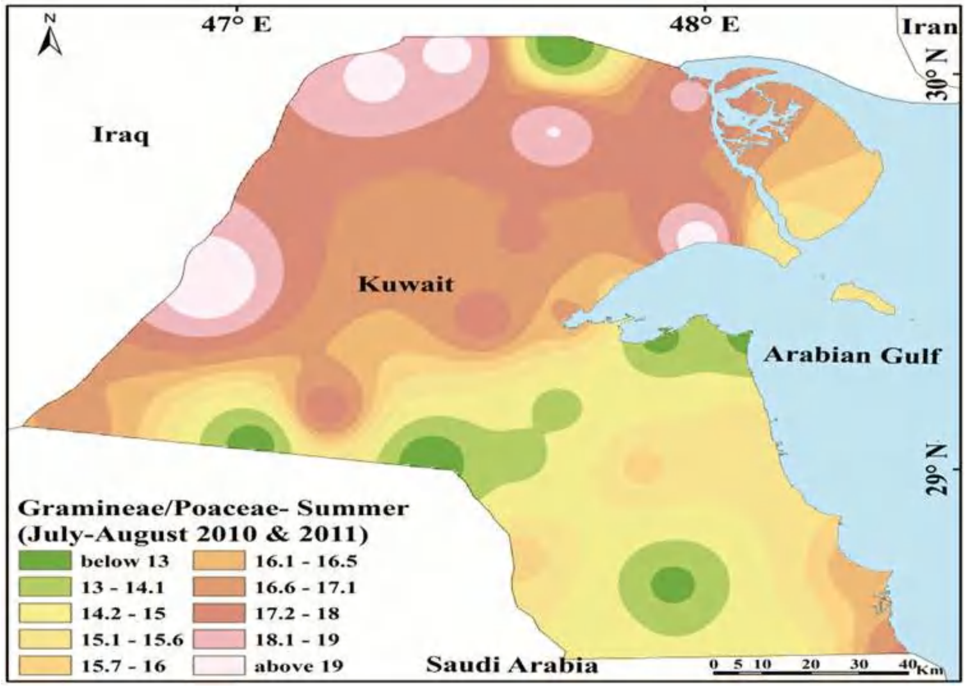

Fig. 7.14 Average percentages of *Gramineae/Poaceae* pollen in dust. Summer (July–August 2010 and 2011)

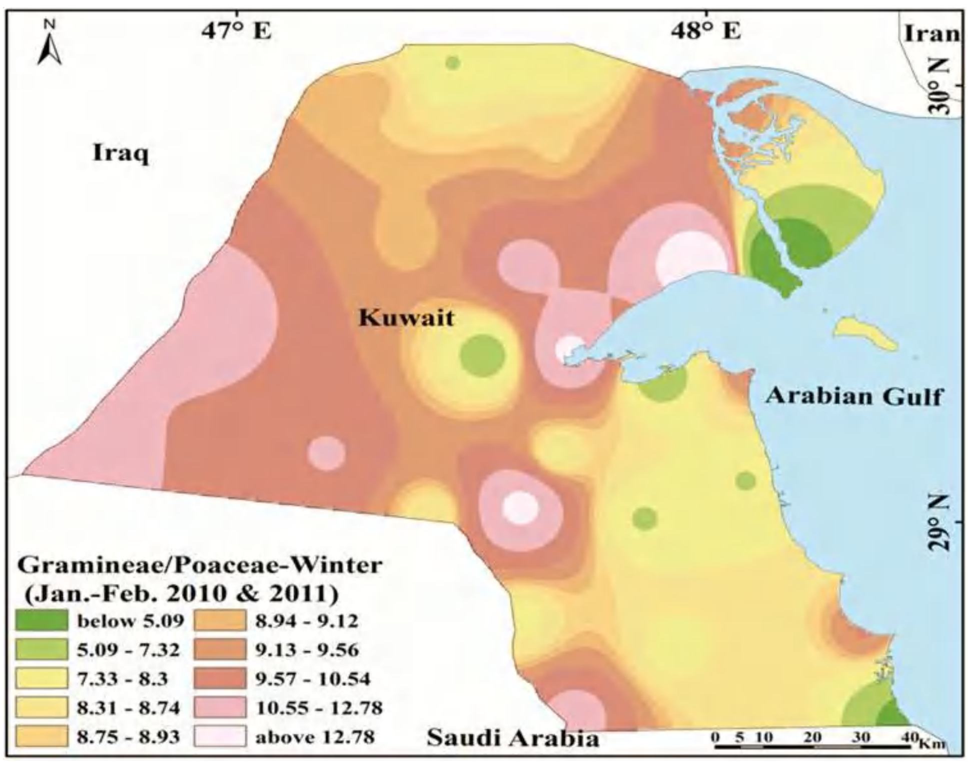

Fig. 7.15 Average percentages of *Gramineae/Poaceae* pollen in dust. Winter (January–February 2010 and 2011)

Gramineae (11.5%). In summer 2011, nearly the same dominance percentage occurred (*Chenopodiaceae*, 33%; *Leguminosae*, 24%; *Cyperaceae*, 19.4%; and *Gramineae*, 18.9%) (Fig. 7.14).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Ubayriq Ratqah Jal Al Zur Liyah Khiran	Dibdibah Abdulli Qurain Kabd Shuwaikh

Gramineae/Poaceae dominated in most desert areas but was maximum in areas such as Liyah, Gudhi, and Kabd. The maximum and minimum counts of *Gramineae/Poaceae* distribution were similar in spring and summer, the only difference being the number of detections, as it was the highest in winter, when these plants cover huge areas in Kuwait and in upwind regional areas in Iraq. The maximum counts reached up to 12.78 during winter, even before the flourishing of the dominating plant species. In the winters of 2010 and 2011, *Gramineae/Poaceae* reached 7.6% and 10%, respectively, in counts (Fig. 7.15).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Gudhi Mutla Kabd Khur Al-Fawaris Shegaya	Ratqah Subiyah Jal Al-Atraf Burqan Khiran

Leguminosae (Fabaceae) was the second most abundant family that flourished during autumn and spring. The highest distribution was recorded during fall 2009 and 2010 (up to 54%) in the extreme western side of the country, and the lowest pollen concentrations were recorded in the west of Kuwait (fall 2009), eastern Kuwait (winter 2010), and southern Kuwait (spring 2011 and summer 2011). The dominant genera in Kuwait are *Acacia, Astragalus, Coronilla, Lotus, Medicago, Prosopis, Scorpiurus, Trigonella* and *Astragalus* in Liyah, while *Coronilla* dominates in open, deteriorated desert, such as in Shegaya and Salmi. *Chenopodiaceae* and *Leguminosae* together comprise over 70% of the total pollen during fall. In spring 2010 and 2011, the *Leguminosae* pollen families had higher percentages, with 11.7% and 12%, respectively (Fig. 7.16).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Um Niqa Khiran Ubayriq Shegaya Gudhi	Dibdibah Kabd Um Qudayr Qurain Um Eish

Leguminosae (Fabaceae) had the highest pollen count in small areas in summer, extending from Abdulli to Liyah. As most of the native plant species within this family flourish during fall and spring, summer may also contain appreciable amounts of pollen. The lowest pollen concentrations were recorded in southern Kuwait (spring 2011 and summer 2011). *Acacia, Astragalus, Coronilla, Lotus, Medicago, Prosopis, Scorpiurus, Trigonella*, and *Astragalus* are the dominant

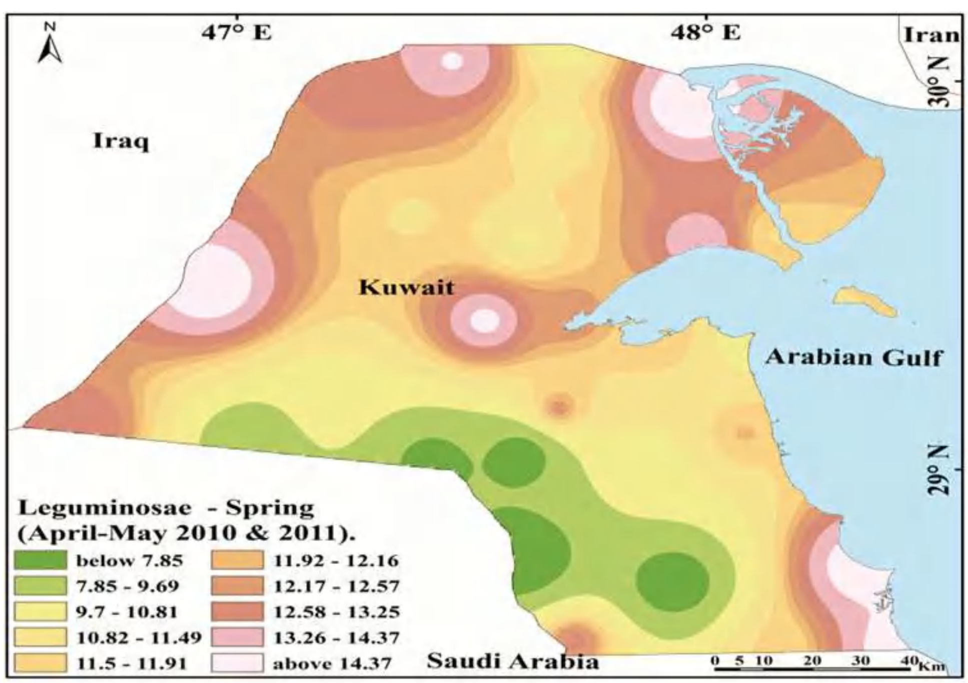

Fig. 7.16 Average percentages of *Leguminosae* pollen in dust. Spring (April–May 2010 and 2011)

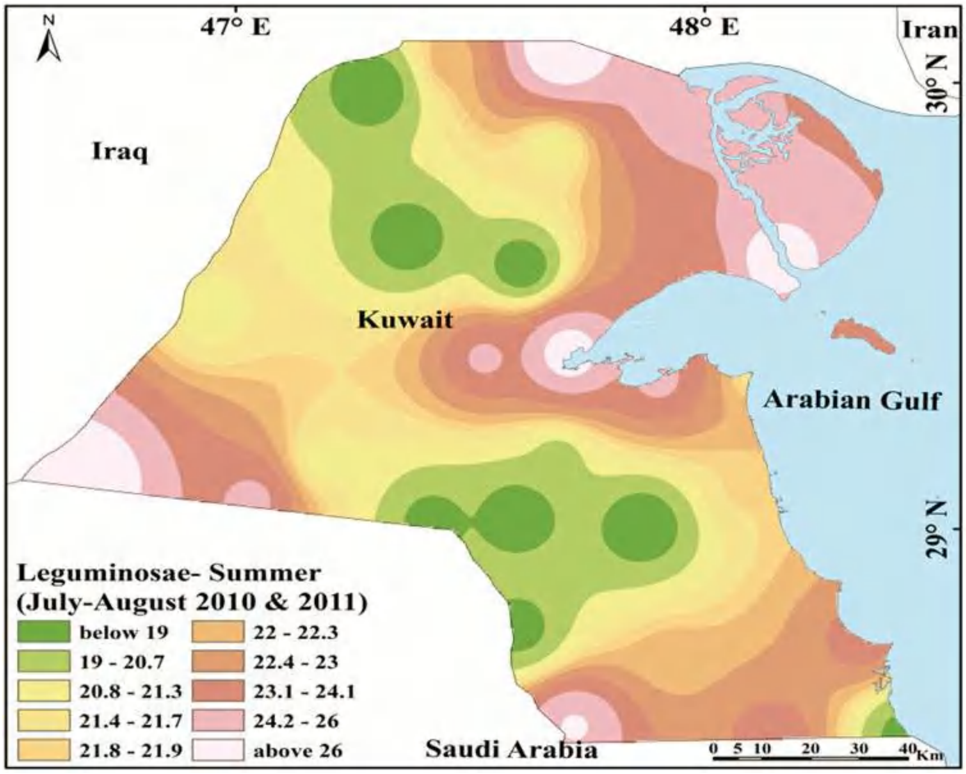

Fig. 7.17 Average percentages of *Leguminosae* pollen in dust. Summer (July–August 2010 and 2011)

genera from this plant family and dominated in Abdulli, Shegaya, and Salmi. In summer and fall, *Chenopodiaceae* dominated, followed by *Leguminosae*. In summer 2010, the highest counts were of *Chenopodiaceae* (32.8%) and *Leguminosae* (23.2%). The same trend was observed in summer 2011, with nearly the same dominance percentage (*Chenopodiaceae*, 33%; *Leguminosae*, 24%) (Fig. 7.17).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Mutla	Ratqah
Subiyah	Huwaymilyah
Abdulli	Kabd
Khur Al-Fawaris	Burqan
Shegaya	Khiran

Leguminosae (Fabaceae) in winter had a similar distribution to summer and springtime. The highest counts were in an area that extends from Abdulli to Liyah. As most of the native plant species within this family flourish during autumn and spring, summer may also contain appreciable amounts of pollen. The lowest pollen concentrations were recorded in the Liyah area (spring 2011 and summer 2011). The *Acacia, Astragalus, Coronilla, Lotus, Medicago, Prosopis, Scorpiurus,* and *Trigonella*. *Astragalus* species are the dominant genera in this plant family, and it is dominant in Wafra Farm, Shegaya, and Salmi. In winter 2010 and 2011, *Chenopodiaceae* dominated the counts (52% and 43%, respectively), followed by *Leguminosae* (12.2% and 18.8%, respectively) (Fig. 7.18).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Salmi	Ras Ezur
Wafra Farm	Liyah
Dibdibah	Doha
Ratqah	Jreshan
Shegaya	Sulaybiyah

The Malvaceae family contains nearly 243 genera and at least 4,225 species of trees, shrubs, and herbs. Kuwait is home to three herbs from the Malvaceae family, namely *Althaea ludwigii*, *Malva nicaeensis,* and *Malva parviflora*. All the flowers bloom in April. During spring 2010 and 2011, the abundant pollen families belonging to *Cyperaceae* (33.6%) are followed by *Chenopodiaceae* (24%), *Gramineae* (19.6%), *Leguminosae* (11.7%), *Plantaginaceae* (4.4%), *Malvaceae* (2.1%), and *Ephedraceae* (1.2%). In spring 2011, the pollen distribution and abundance showed the same trend as in spring 2010, with an abundance of *Cyperaceae* (33.7%), followed by *Chenopodiaceae* (24.9%), *Gramineae* (19.3%), *Leguminosae* (12%), *Plantaginaceae* (3.2%), *Malvaceae* (1.9%), *Ephedraceae* (1.2%), and *Brassicaceae* (1.1%). In the map, above, *Malvaceae* pollen is absent from the northern Kuwait desert but appears with maximum counts in Dibdibah and Ratqah (Fig. 7.19).

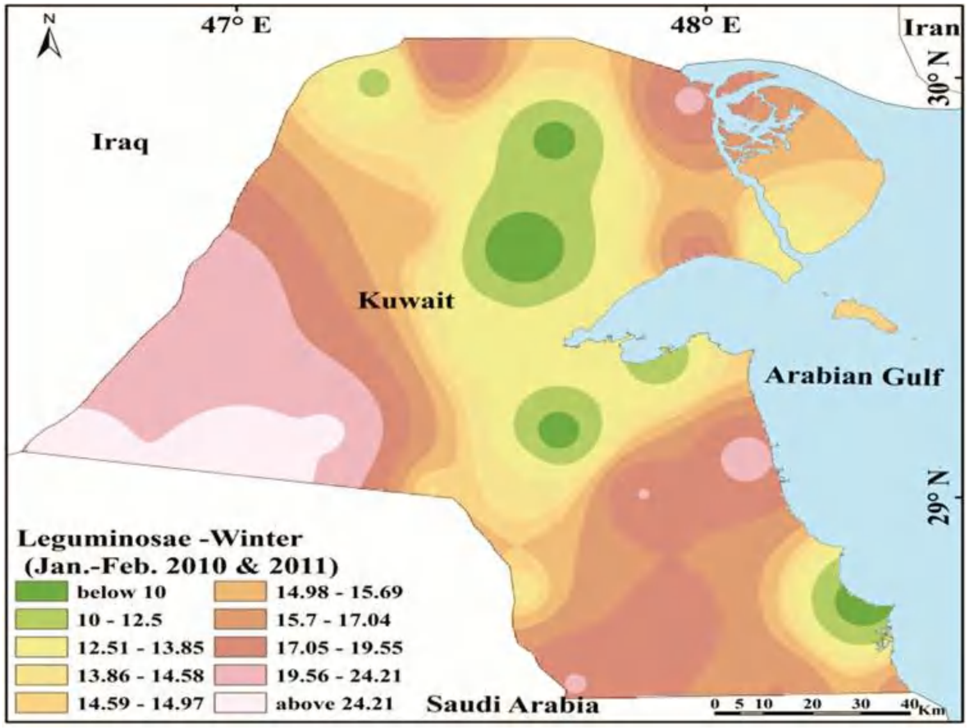

Fig. 7.18 Average percentages of *Leguminosae* pollen in dust. Winter (January–February 2010 and 2011)

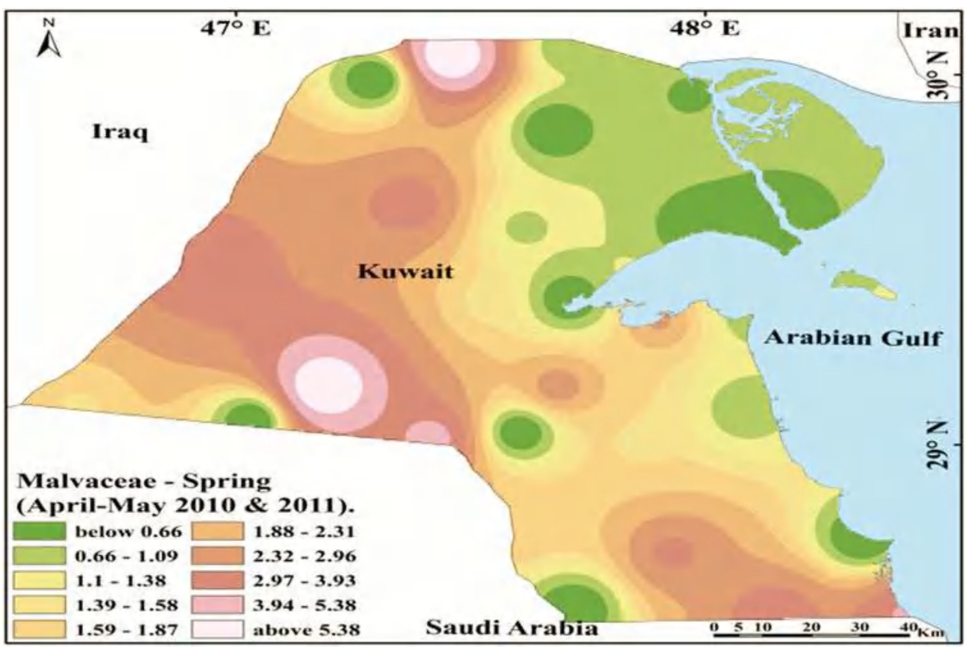

Fig. 7.19 Average percentages of *Malvaceae* pollen in dust. Spring (April–May 2010 and 2011)

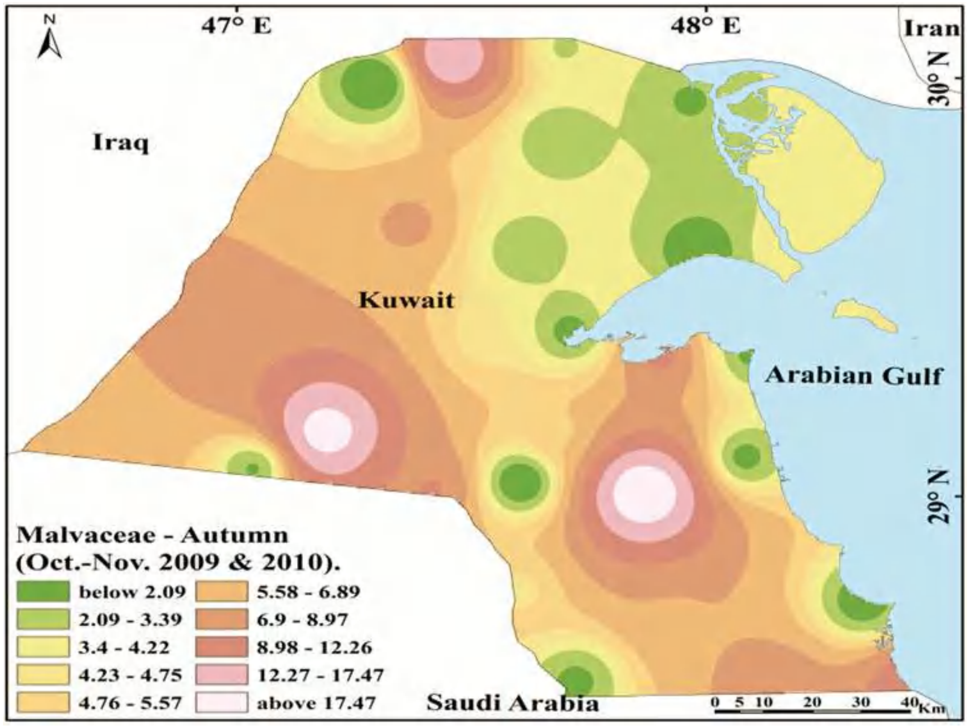

Fig. 7.20 Average percentages of *Malvaceae* pollen in dust. Autumn (October–November 2009 & 2010)

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Ratqah Dibdibah Um Al Madafi' Ubayriq Wafra Farm	Subiyah Shuaiba Doha Kur Al-Fawaris Shuaiba

The three major herbs from the *Malvaceae* family present in the region are *Althaea ludwigii*, *Malva nicaeensis,* and *Malva parviflora*. The *Malvaceae* family contains about 243 genera and at least 4,225 species of trees, shrubs, and herbs. In Kuwait, All flowers bloom during April. In fall 2010, the highest pollen counts were of *Chenopodiaceae* (57%), followed by *Leguminosae* (22%), *Plantaginaceae* (7%), *Malvaceae* (7%), and *Gramineae* (6.5%). The distribution map for *Malvaceae* pollen during fall shows an abundance level around farms (Abdulli and Wafra Farms) and is still present in Salmiya, coming from regional sources from the coast (Fig. 7.20).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Ratqah Dibdibah Salmi Burqan Wafra Farm	Khur Fawaris Ratqah Gudhi Um Niqa Jal Al Zur

The *Malvaceae* three major herbs present in the region are *Althaea ludwigii*, *Malva nicaeensis,* and *Malva parviflora*. In summer 2010, the highest counts were of *Chenopodiaceae* (32.8%), followed by *Leguminosae* (23.2%), *Cyperaceae* (18.7%), *Gramineae* (11.5%), *Plantaginaceae* (4.3%), and *Malvaceae* (2.3%). The same trend was observed in summer 2011, with nearly the same dominance percentage (*Chenopodiaceae*, 33%; *Leguminosae*, 24%; *Cyperaceae*, 19.4%; *Gramineae*, 18.9%; *Plantaginaceae*, 3.5%; and *Malvaceae*, 1.8%). In the map, above, *Malvaceae* pollen appears with the maximum count in the northern Kuwait desert but is absent from urban areas Subiyah and Abdulli (Fig. 7.21).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Ratqah Huwaymilyah Salmi Dibdibah Khiran	Salmiya Subiyah Abdulli Um Niqa Kabd

Plantaginaceae pollens were majorly present in the pollen traps and originate primarily from *Plantago* species (*amplexicaulis*, *boissieri*, *ciliata*, *coronopus*, *lanceolata*, *notate*, *ovata,* and *psammophila*). The most-detected *Plantaginaceae* pollens were found in spring. In spring 2010 and 2011, the pollen families belonging to *Plantaginaceae* reached up to 4.4% and 3.2%, respectively. The pollen appeared only in preserved areas such as Sabiyah, Liyah, and Kabd (Fig. 7.22).

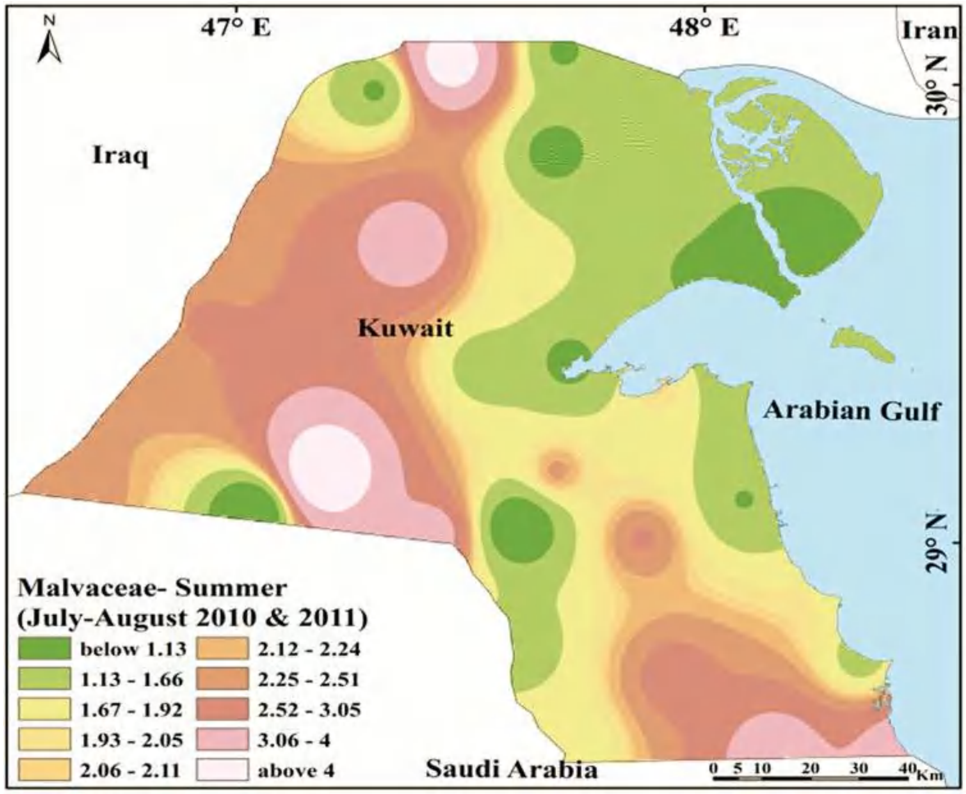

Fig. 7.21 Average percentages of *Malvaceae* pollen in dust. Summer (July–August 2010 and 2011)

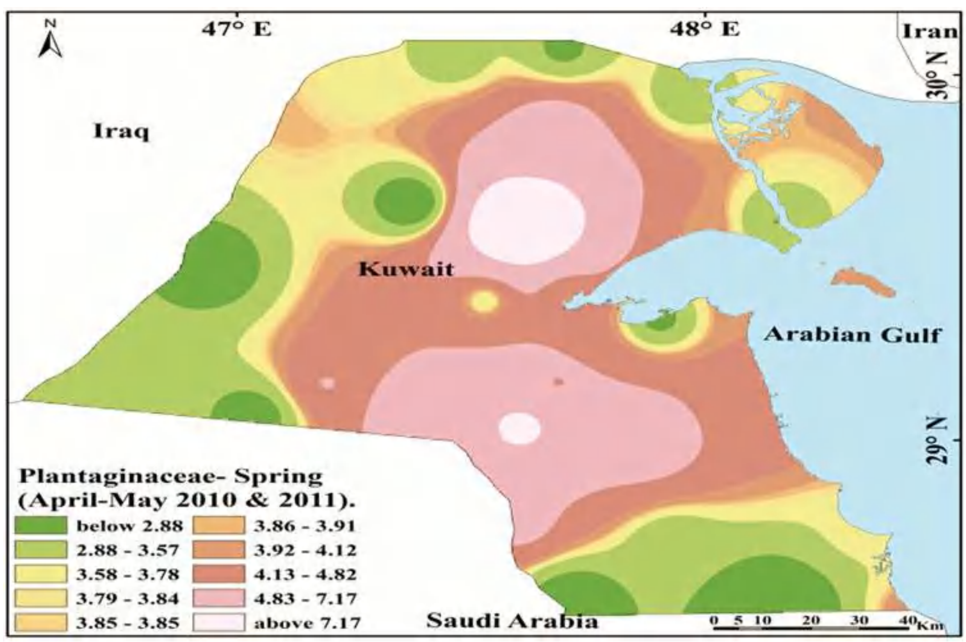

Fig. 7.22 Average percentages of *Plantaginaceae* pollen in dust. Spring (April–May 2010 and 2011)

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Liyah Sulaybiyah Liyah Dibdibah Kabd	Ratqah Huwaymilyah Salmi Um Niqa Khiran

Plantaginaceae pollen originates mainly from *Plantago* species (*amplexicaulis*, *boissieri*, *ciliata*, *coronopus*, *lanceolata*, *notata*, *ovata,* and *psammophila*). In summer 2010, the highest counts were recorded for *Chenopodiaceae* (32.8%), followed by *Leguminosae* (23.2%), *Cyperaceae* (18.7%), *Gramineae* (11.5%), and *Plantaginaceae* (4.3%). The same trend was observed in summer 2011, with nearly the same dominance percentage (*Chenopodiaceae*, 33%; *Leguminosae*, 24%; *Cyperaceae*, 19.4%; *Gramineae*, 18.9%; and *Plantaginaceae*, 3.5%). The distribution of *Plantaginaceae* pollen was similar to that in spring. The highest counts were around Sabah Al-Ahmed National Reserve (a preserved area) (Fig. 7.23).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Liyah Kabd Um Eish Sulaybiyah Gudhi	Ratqah Salmi Abdulli Mutla Wafra Farm

Plantaginaceae pollens were majorly present in traps mainly containing *Plantago* species (*amplexicaulis*, *boissieri*, *ciliata*, *coronopus*, *lanceolata*, *notata*, *ovata,* and *psammophila*). In fall (October to November) 2010 and 2011, low pollen counts were observed for *Plantaginaceae* (7% and 5.7%, respectively). The lowest counts of *Plantaginaceae* were noted during fall, and it appeared only in preserved areas, such as Liyah, Kabd, and Shuaiba (Fig. 7.24).

Areas with high pollen in dust concentration	Areas with low pollen in dust concentration
Liyah Huwaymilyah Kabd Um Qudayr Shuaiba	Ratqah Abdulli Burqan Um Niqa Salmi

The local flora are the main source of the pollen load, and the concentration depends on the amount of vegetation around each station, except for very low percentages (2–3%) of *Pinaceae* pollen recorded in the north and northwest of Kuwait, which can be interpreted as being transported by the dominant northwesterly winds from regional sources. The nearest pine trees on the regional scale are situated in northern Iraq and Syria, and in Lebanon and Turkey (Fig. 7.25).

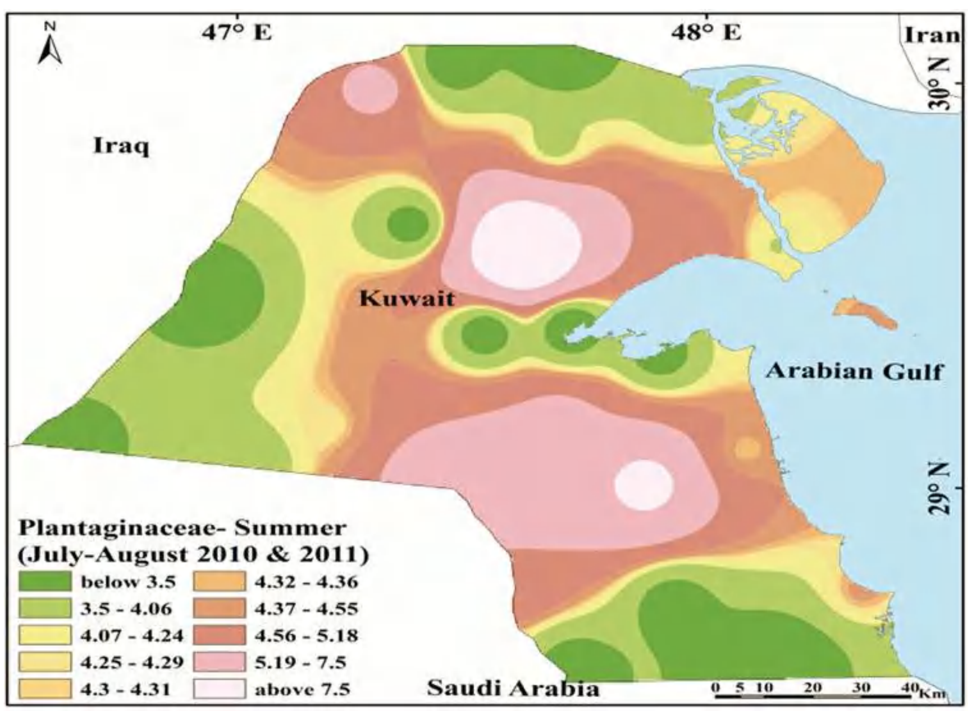

Fig. 7.23 Average percentages of *Plantaginaceae* pollen in dust. Summer (July–August 2010 and 2011)

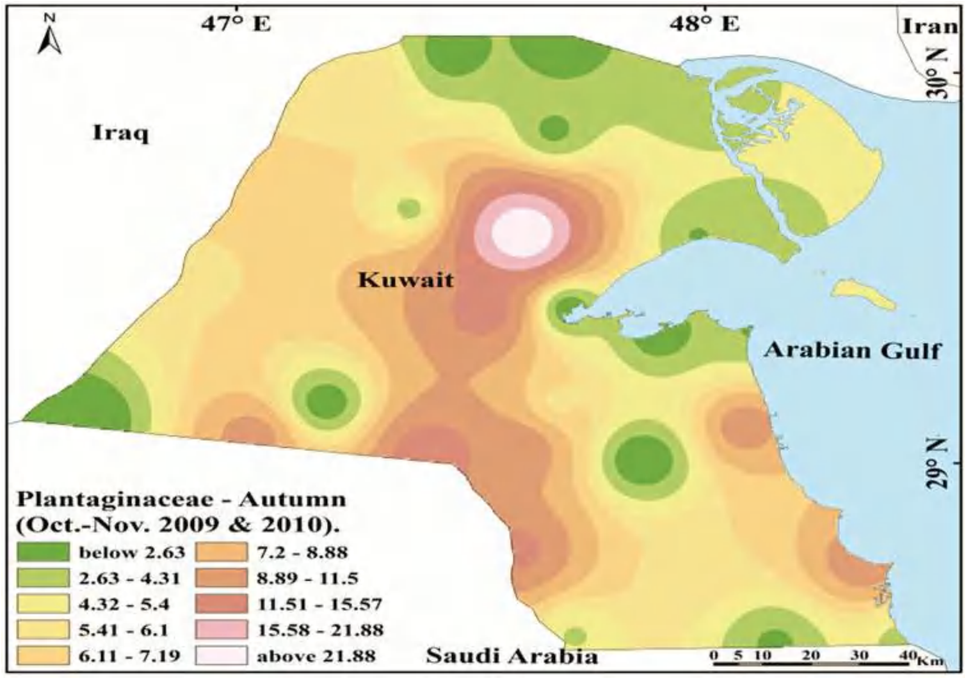

Fig. 7.24 Average percentages of *Plantaginaceae* pollen in dust. Autumn (October–November 2009 and 2010)

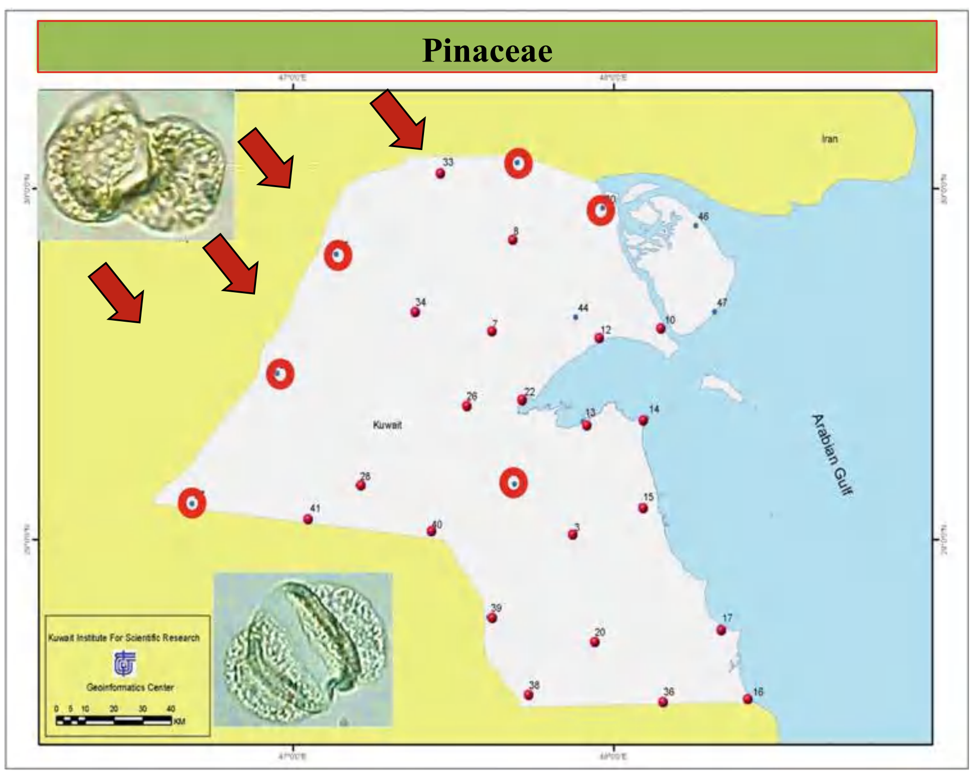

Fig. 7.25 Map showing the sites of *Pinaceae* pollen

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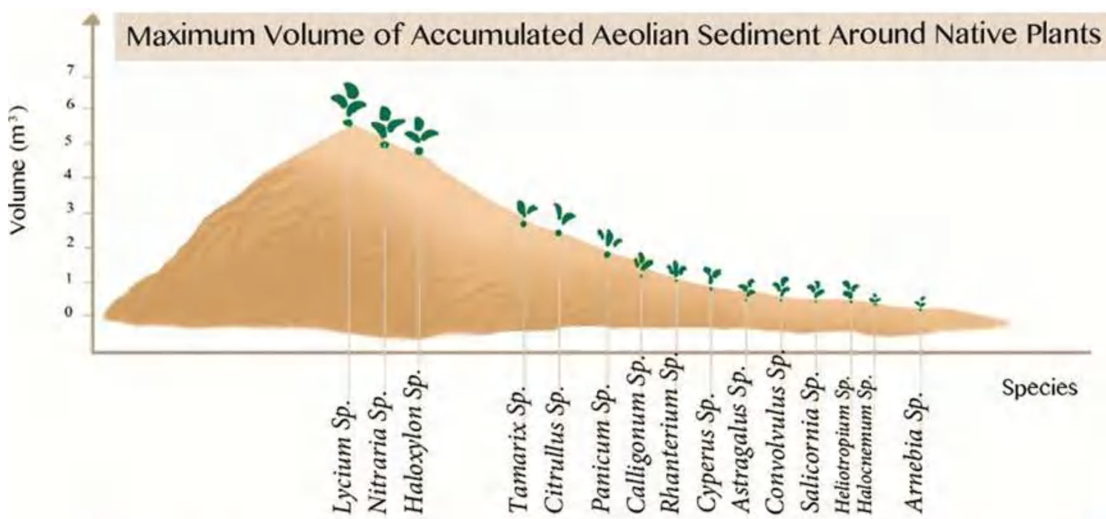

	Lycium Sp.	*Nitraria Sp.*	*Haloxylon Sp.*	*Tamarix Sp.*	*Citrullus Sp.*	*Panicum Sp.*	*Calligonum Sp.*	*Rhanterium Sp.*	*Cyperus Sp.*	*Astragalus Sp.*	*Convolvulus Sp.*	*Salicornia Sp.*	*Heliotropium Sp.*	*Halocnemum Sp.*	*Arnebia Sp.*
Minimum (m^3)	0.14	0.67	0.08	0.24	0.05	0.33	0.04	0.03	0.01	0.01	0.002	0.01	0.01	0.01	0.001
Average (m^3)	1.18	1.99	1.26	1.05	0.64	0.95	0.3	0.19	0.19	0.19	0.09	0.06	0.1	0.06	0.004
St. Deviation	1.3	1.33	1.21	0.59	0.45	0.46	0.35	0.24	0.21	0.13	0.12	0.09	0.08	0.05	0.002

8 Other Properties (BET Surface Area, Conductivity, Organic Matter, and pH)

Modi Ahmed and Khaliq Beg

Abstract

- Brunauer, Emmett, and Teller (BET) test were applied to dust samples in which samples (BET) surface area is highly related to the roundness of dust particles. The higher angularity and low roundness of the dust particles show a higher (BET) surface area. The roundness is also related to the particle size distribution and mineralogical composition.
- The electrical conductivity test relates very well with the chemical and physical properties of dust samples in the transmission of an electrical current.
- The organic matter content was measured using the ignition method and the pH of the samples was recorded.
- Maps of the distribution of high and low BET concentrations, electrical conductivity EC, organic matter content, pH.

Methods

BET Surface Area

The BET surface area is a specific measurement of the area of the dust particle surface. BET surface area resolute BET through gas physical adsorption of the dust particle surface by calculating the mass of adsorbed gas corresponding to a monomolecular layer on the particle surface. The gas physical adsorption results from weak van der Waals forces between the adsorbent surface area of the tested dust particles and the adsorbed nitrogen gaseous molecules. The determination is frequently carried out at the temperature of liquid nitrogen. The mass of gas adsorbed can be determined by either a volumetric or continuous flow process. The measurement of the BET surface area for dust particles was made using a COULTER-SA 3100 (Fig 8.1).

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Fig. 8.1 COULTER-3100 for measuring the BET surface area for dust particles

Electrical Conductivity

Electrical conductivity is a measurement that relates very well with the chemical and physical properties of dust samples. Electrical conductivity is the capability of a sample to transmit an electrical current, and it is normally expressed in units of deciSiemens per meter (dS/m). The electrical conductivity measurements can be expressed in milliSiemens per meter (mS/m) also, which is 100 times less than deciSiemens per meter.

pH

The dust samples were mixed in 125 ml of distilled water. The mixture was shaken in an electrical shaker for one hour and then left to settle for one hour. The resulting suspension was used for pH determination (Fig 8.2).

Fig. 8.2 Conductivity and pH meter used for dust samples

Organic Matter

The organic matter was measured using the ignition method, in which the dust sample was weighed, dried in an oven at 60 C for 24 h, weighed again, and then washed in a muffle furnace at 400 °C for four hours. The organic matter was calculated by using the difference of the initial weight and the final weight multiplied by 100/58. Organic matter % = organic carbon % × 11/58.

BET-Surface Area

The BET surface area is highly related to the roundness of dust particles. The higher angularity and low roundness of the dust particles reveal a higher BET surface area. The roundness is also related to the particle size distribution and mineralogical composition. Dust samples with smaller size fractions and lower quartz percentages have higher values of BET surface area. The dust samples in the northeastern part of Kuwait and near the coastal area have higher BET surface areas, with values of more than 12 m^2/g. This result is attributed to geographical reasons, as those areas with high BET surface area are close to the Mesopotamian Floodplain and Al-Ahwar areas in Iraq, as dust coming from those areas is low in quartz and high in carbonates, feldspars, clay, and heavy minerals. Furthermore, the dust samples in summertime are expected to have a low BET surface area compared with winter (Fig. 8.3).

Areas with high BET concentration	Areas with low BET concentration
Abdulli	Warba Island
Subiyah	Khur Fawaris
Jal Al Zur	Shegaya
Khiran	Dibdibah
Sulaybiyah	Mutla

Conductivity

Electrical conductivity (EC) is a measurement of the dissolved material associated with or attached to dust samples, which relates to the ability of the material to conduct an electrical current. More salt or evaporated minerals, such as halite, gypsum, and anhydrite, cause higher values of EC. High conductivity is present on Bubiyan Island and the southern sector of Kuwait, as most sabkhas are present. Sabkhas contain salt minerals that cause an increase in conductivity. The areas extending from Jirashan in the northwest, near the Iraqi border, to northern Kuwait Bay displayed minimum values of conductivity readings (Fig. 8.4).

Areas with high conductivity concentration	Areas with low conductivity concentration
Bubiyan Island	Warba Island
Failaka Island	Liyah
Kabd	Shegaya
Um Qudayr	Jal Al Zur
Khur Fawaris	Mutla

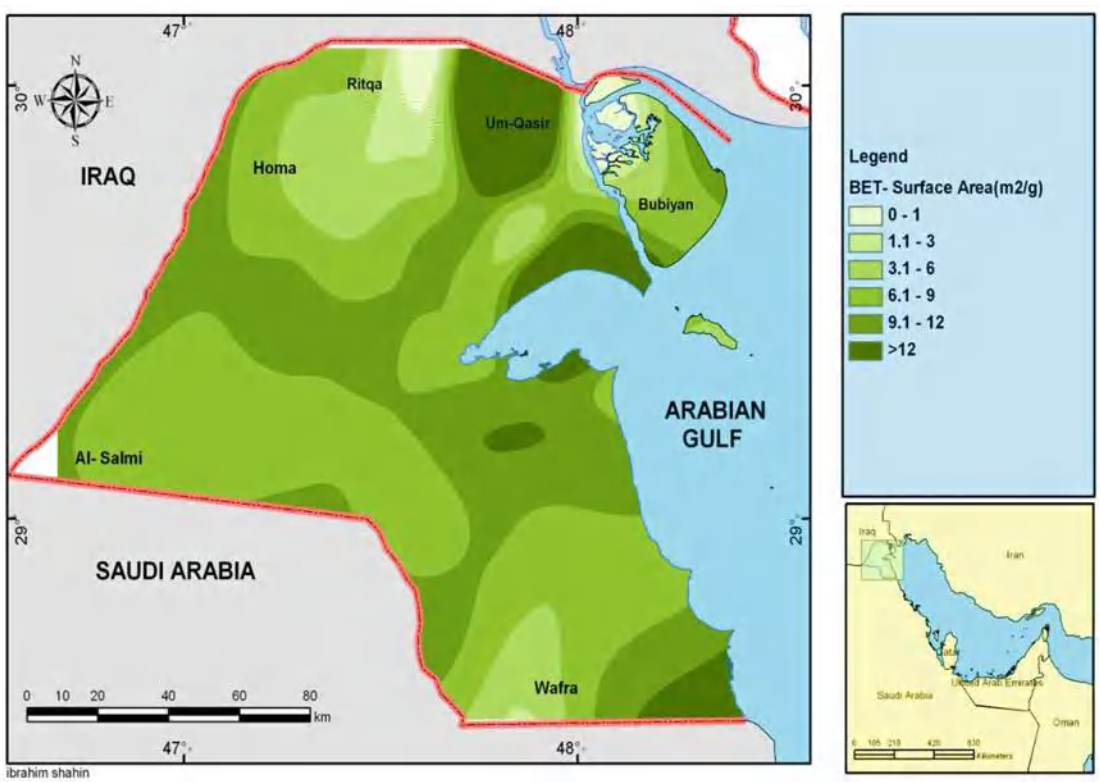

Fig. 8.3 Surface area distribution of dust in Kuwait

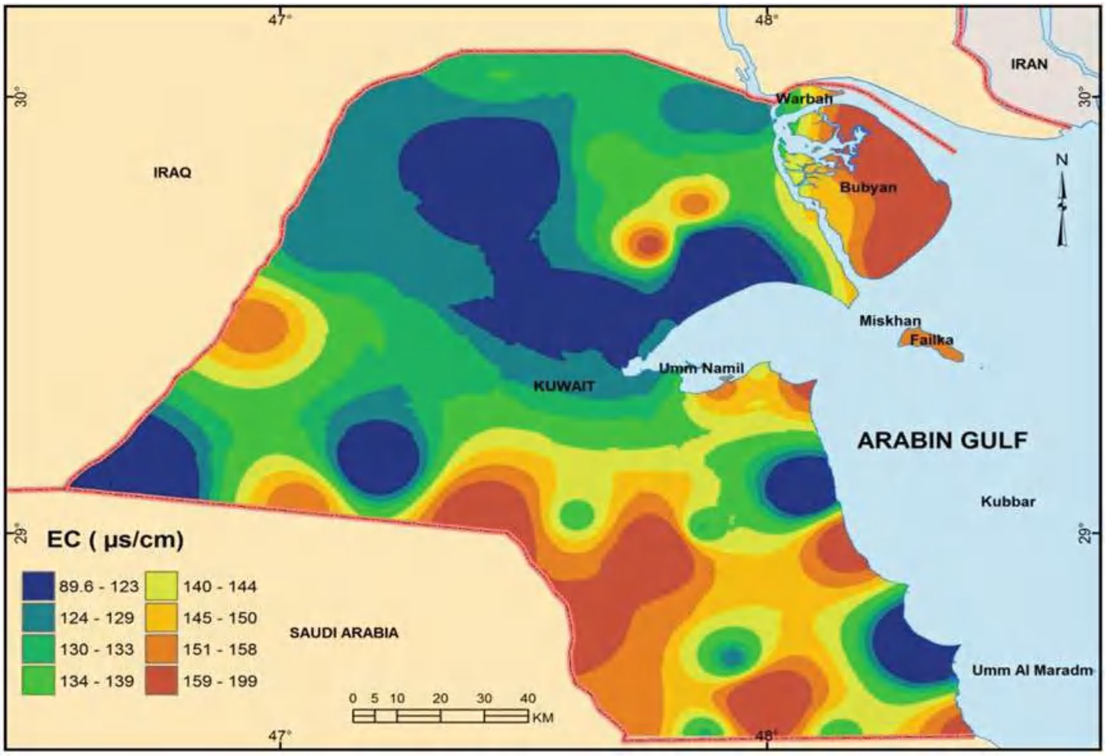

Fig. 8.4 Conductivity area distribution for dust in Kuwait

Organic Matter

Organic matter is measured with reference to the total weight percentage for the dust samples. The values were restricted, from 1.38% to about 9%. The highest percentages of dust values containing organic matter within the dust samples were in the northeastern part of Kuwait and around farms. The presence of high organic matter percentages in dust samples collected in the northeastern parts of Kuwait is attributed to the type of dust, which mostly originates from the Mesopotamian Floodplain. Lower percentages were in the west and northwest of Kuwait. Compared with other dust in the world, deposited dust in Kuwait can be classified as being rich in organic matter. Therefore, dust plays a major role in maintaining the ecological system in the region, and the organic matter in dust is essential, mainly to the marine environment (Fig. 8.5).

Areas with high organic matter concentration	Areas with low organic matter concentration
Bubiyan Island	Ubayriq
Dibdibah	Khur Fawaris
Um Niqa	Salmi
Failaka Island	Shegaya
Wafra Farms	Burqan

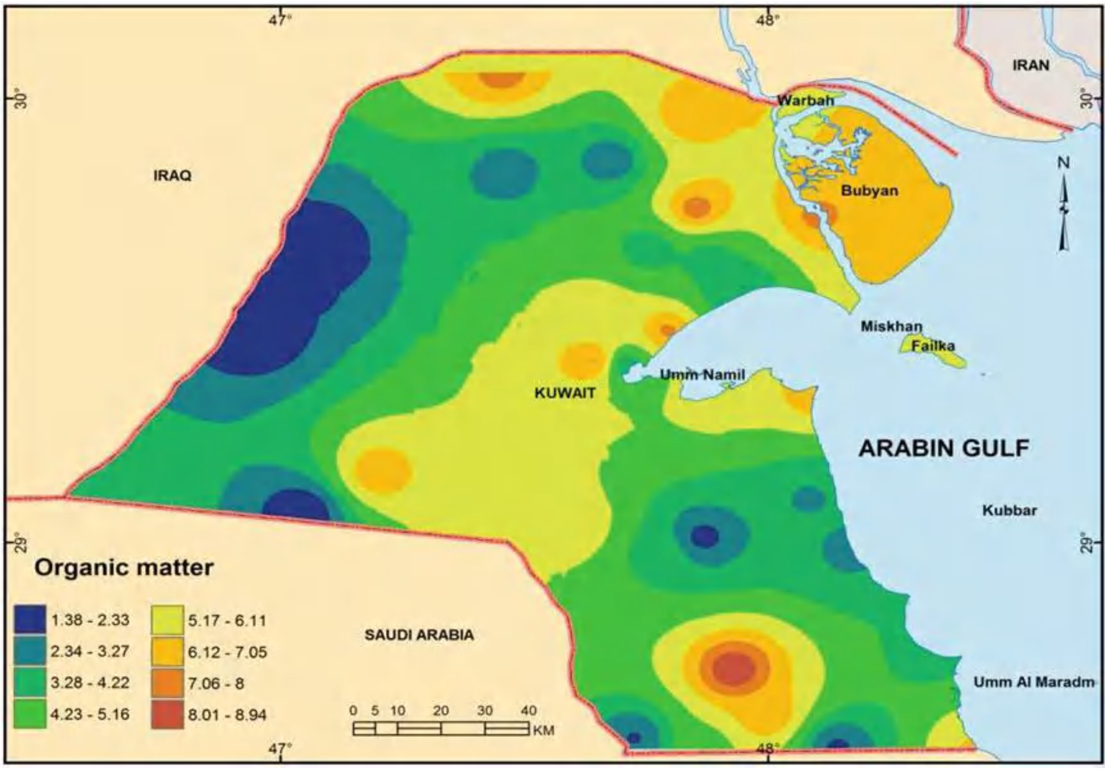

Fig. 8.5 Organic matter area distribution for dust in Kuwait

pH

The dust is more basic than acidic. The variation in pH values is from 7.4 to 8.1. The highest values are present in three areas, namely Huwamilyah, Um Al-Qawatti, and Atraf, while the lowest are present in Jirashan, Shuaiba, Khur Fawaris, and Um Niqa.

These results might indicate that dust occurring in the northwest, from the Western Desert of Iraq, is more basic than the dust coming from other directions, mainly the Mesopotamian Foodplain, Iran, and Saudi sides. The pH level might be related to humidity, as Saudi source areas of dust are more humid (Fig. 8.6).

Areas with high Ph concentration	Areas with low Ph concentration
Bubiyan Island	Shuaiba
Huwaymilyah	Khur Fawaris
Khiran	Ratqah
Atraf	Dibdibah
Um Al-Qawatti	Um Niqa

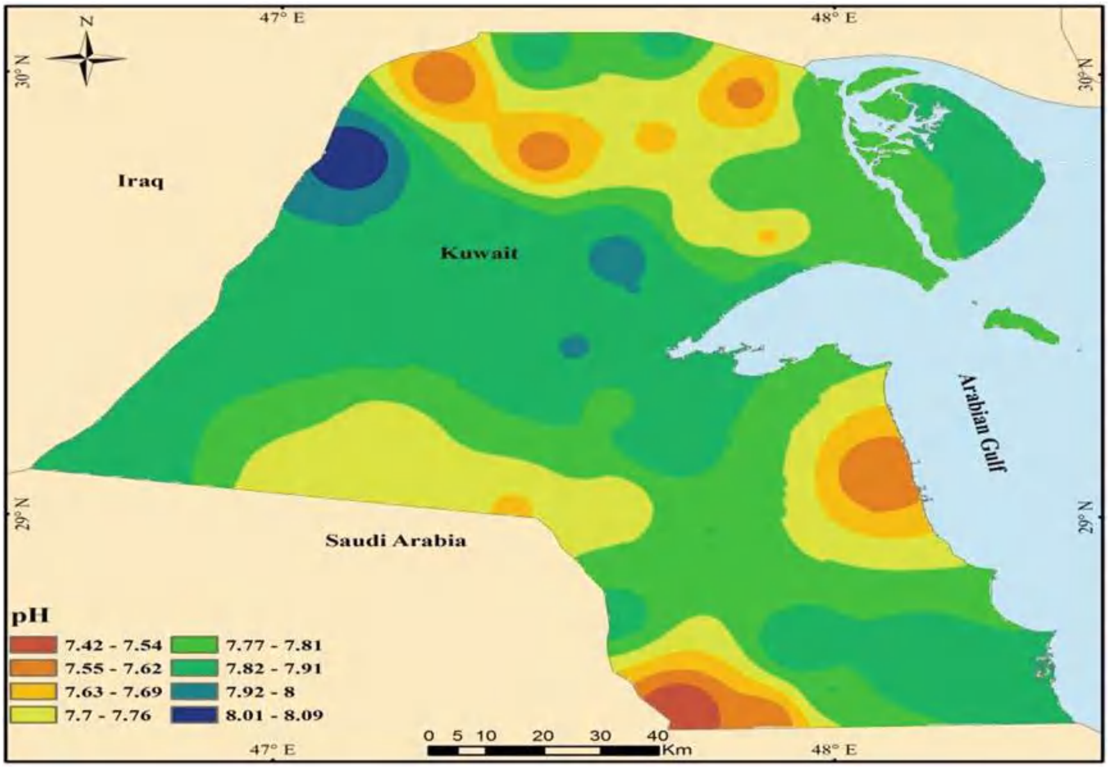

Fig. 8.6 Ph distribution for dust in Kuwait

Spectro Absorption

9

Safaa Al-Awadhi and Mustafa Al-Shemali

Abstract

- Ultraviolet–visible UV-VIS. Varian Bio Cary 100 UV–VIS instrument was used for measuring the spectrum of dust samples.
- The certified materials according to Lab sphere SRS. 99–020 were used and the dust samples were placed in a cuvette (10 mm) and placed on the diffuse reflectance accessory.
- Measurement was done with respect to the reference. The UV–VIS spectra cover the regions from 900 to 190 nm which includes the near-infrared region, visible light regions, and ultraviolet regions.
- The FT-IR data shows the different chemical content of dust in the scanning of what possible compounds can be found in dust particles for required further analysis.
- The dust absorption of the light spectrum in Kuwait was revealed in maps according to seasons showing higher and lower concentrations of light absorption of ultraviolet, violet, blue, cyan, green, yellow, orange, red, infrared.

Introduction

Sun produces different types of radiation that travel through space to the earth, as well as to other planets in the solar system. The atmospheric layers protect the earth from much of this radiation. Some radiation penetrates the atmosphere to reach the earth, however, such as infrared, visible light, ultraviolet rays, and etc.

A small amount of solar radiation is essential for many chemical life reactions for humans; however, when animals and plants are exposed to high doses of radiation, this is harmful. For example, sunstroke occurs when humans are exposed to long periods of solar radiation, and it can cause death. In other cases, such exposure causes skin burns and cancer. Drying plants occur when plants are exposed to the sun for long periods, in addition to facing hot winds during the summer (Al-Enezi et al. 2014; Al-Dousari et al. 2016).

Dust helps to protect the earth by absorbing and reflecting some of the sun's radiation, which explains why, when a dust storm is heavy and lasts for a long period, the temperature is reduced. The absorbance of light depends on the constituent compounds of dust. The dust compound depends on the culture of the areas the carrier wind crosses. Although dust causes many problems, such as reduced vision sight and breathing issues (Al-Dousari et al. 2014; Subramaniam et al. 2015; Subramaniam and Al-Dousari 2014), it reduces the sun's heat and direct interaction with objects on earth. Below are maps that illustrate dust absorption of the sunlight during different seasons in Kuwait.

Methodology

Ultraviolet–visible UV–VIS. The Varian Bio Cary 100 UV–VIS instrument was used to measure the spectrum of dust samples. First, the certified material's (Lab sphere SRS. 99–020) background was taken. Second, the dust samples were put in a cuvette (10 mm) and placed on the diffuse

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reflectance accessory. Finally, the measurement was made with respect to the reference. The UV–VIS spectra cover the regions from 900 to 190 nm, which include the near-infrared region, visible light regions, and ultraviolet regions. The data were analyzed using Microsoft Excel to extract the maximum absorption of light radiation frequency.

Furrier Transformer Mid-Infrared FT-MID. The Victor 22 BRUKER instrument was used for this experiment. First, the KBr powder was ground and transferred to the diffuse reflectance holder, then the powder was pressed with a flat plate. Second, the holder was placed inside the experiment accessory installed inside the instrument. Third, the background experiment was run on KBr. Fourth, a very small portion of dust was mixed with ground KBr powder. Finally, the mixture was transferred to the experiment holder and pressed to be measured against the KBr background spectrum. The spectra covered the normal MID-infrared region, from 4000 cm^{-1} to 400 cm^{-1}.

UV Absorption Summer 2010

The ultraviolet light absorbed in summer varies throughout Kuwait. The dust shows a high absorption to UV light near the coast of Kuwait Bay (collector D22 in Kathma) and at Sabah Al-Ahmad Nature Reserve (collector D44 and D45). Along the border with Iraq, the absorption of UV light was very low at dust collector D25 and South Buffer zone D32 (Homa) and D33 (Ritqa). Similarly, the borderline with Saudi Arabia in the southeast border at collector D20 Wafra animal farm, D18 Ras Zur-Wafra, D16 Nuwaissieb, D27 Salmi border zone, and D28 Poultry mid-way Salmi road Abraq all displayed low absorption of UV. In general, the area near Kuwait Bay, which covers Kuwait City and Hawalli City, had a high absorption of UV. The absorbance rate began to reduce toward Jahra City in the north and Ahmadi in the south. The chemical content of the dust near Kuwait Bay has the ability in summer to absorb more UV light than the dust in areas farther away (Fig. 9.1).

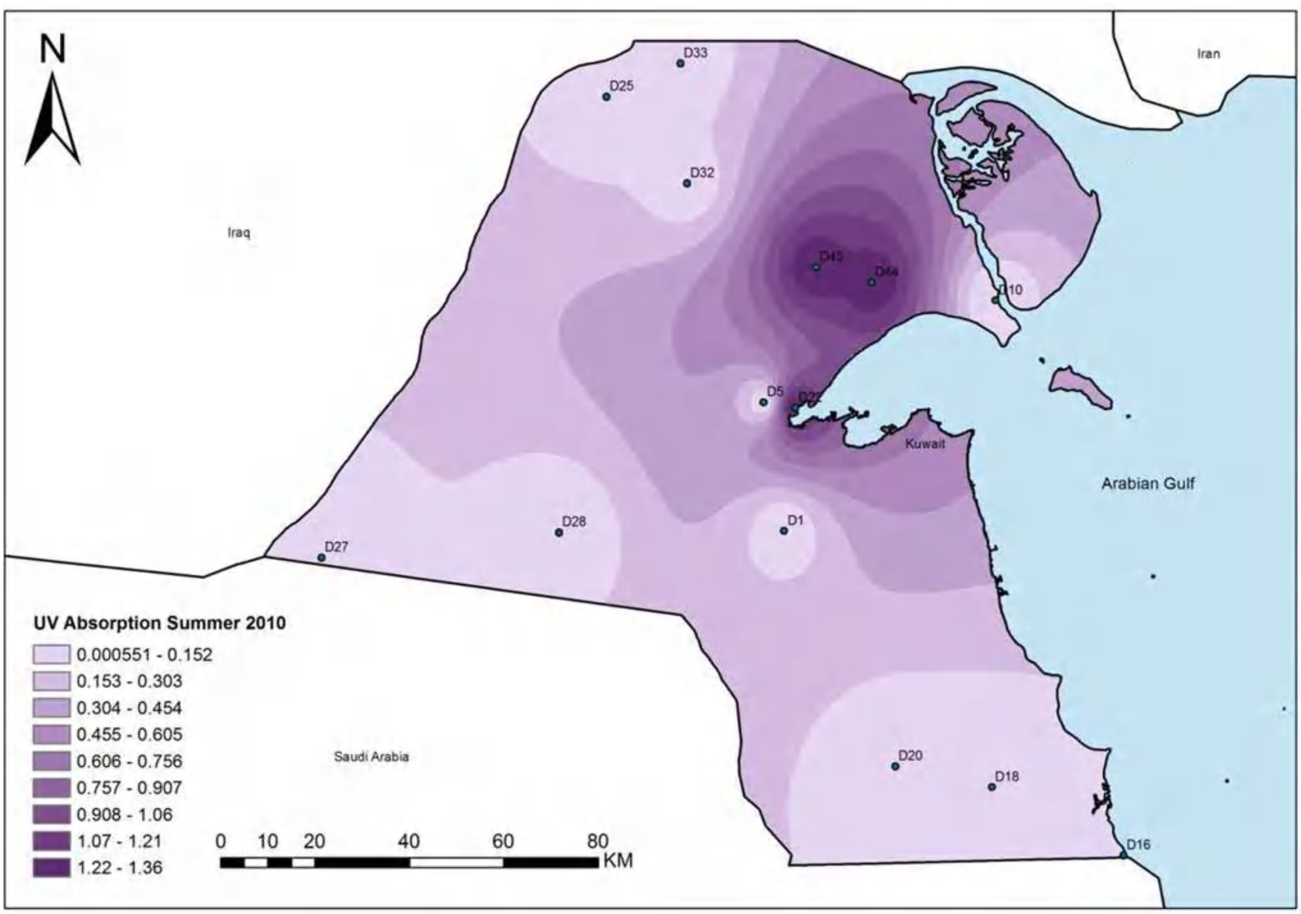

Fig. 9.1 Dust absorption of ultraviolet light in summer 2010

Violet Absorption Summer

The absorbed violet light in summer varies throughout Kuwait. The dust shows high absorption to violet light at Sabah Al-Ahmad Nature Reserve (collectors D44 and D45) and begins to reduce near the coast at Kuwait Bay (collector D22 in Kathma). On the border with Iraq, the absorption of violet light was very low at dust collector D25, the South Buffer zone, D32 Homa, and D33 Ritqa, and on the borderline with Saudi Arabia in the southeast borders at collector D20 Wafra animal farm, D18 Ras Zur-Wafra, D16 Nuwaissieb, D27 Salmi border zone, D28 Poultry mid-way Salmi road Abraq. In general, the area near Kuwait Bay, which covers Kuwait City and Hawalli City, had high absorption of UV. This absorbance capacity begins to reduce toward Jahra City in the north and Ahmadi in the south. The chemical content of the dust near Kuwait Bay has the ability in summer to absorb more violet light than the dust in areas that are situated farther away (Fig. 9.2).

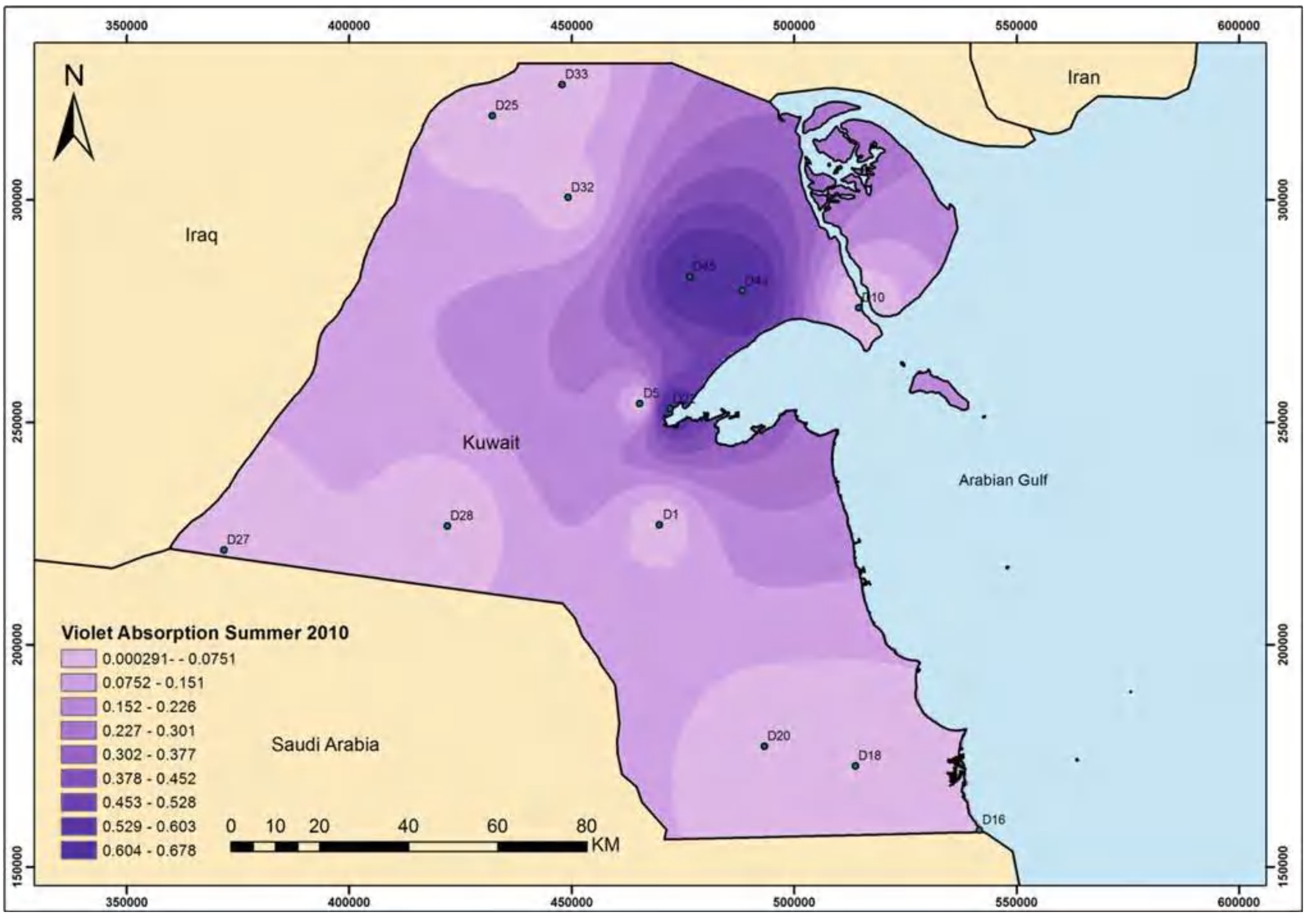

Fig. 9.2 Dust absorption of violet light in summer 2010

Blue Absorption Summer

The blue light in absorbed summer varies throughout Kuwait. The dust shows high absorption of the blue light at Sabah Al-Ahmad Nature Reserve (collectors D44 and D45) and begins to reduce near the coast at Kuwait Bay (collector D22 in Kathma). On the border with Iraq, the absorption of blue light was very low at collector D25 South Buffer zone, D32 Homa, and D33 Ritqa, and along the border with Iraq. The southeast borders at collector D20 Wafra animal farm, D18 Ras Zur-Wafra, D16 Nuwaissieb, D27 Salmi border zone, D28 Poultry mid-way Salmi road Abraq all had low absorption of blue light also. In general, the area near Kuwait Bay, including Kuwait City and Hawalli, had high absorbance, which begins to reduce toward Jahra in the north and Ahmadi in the south. The chemical content of the dust near Kuwait Bay has the ability in summer to absorb more blue light in the dust than areas farther away (Fig. 9.3).

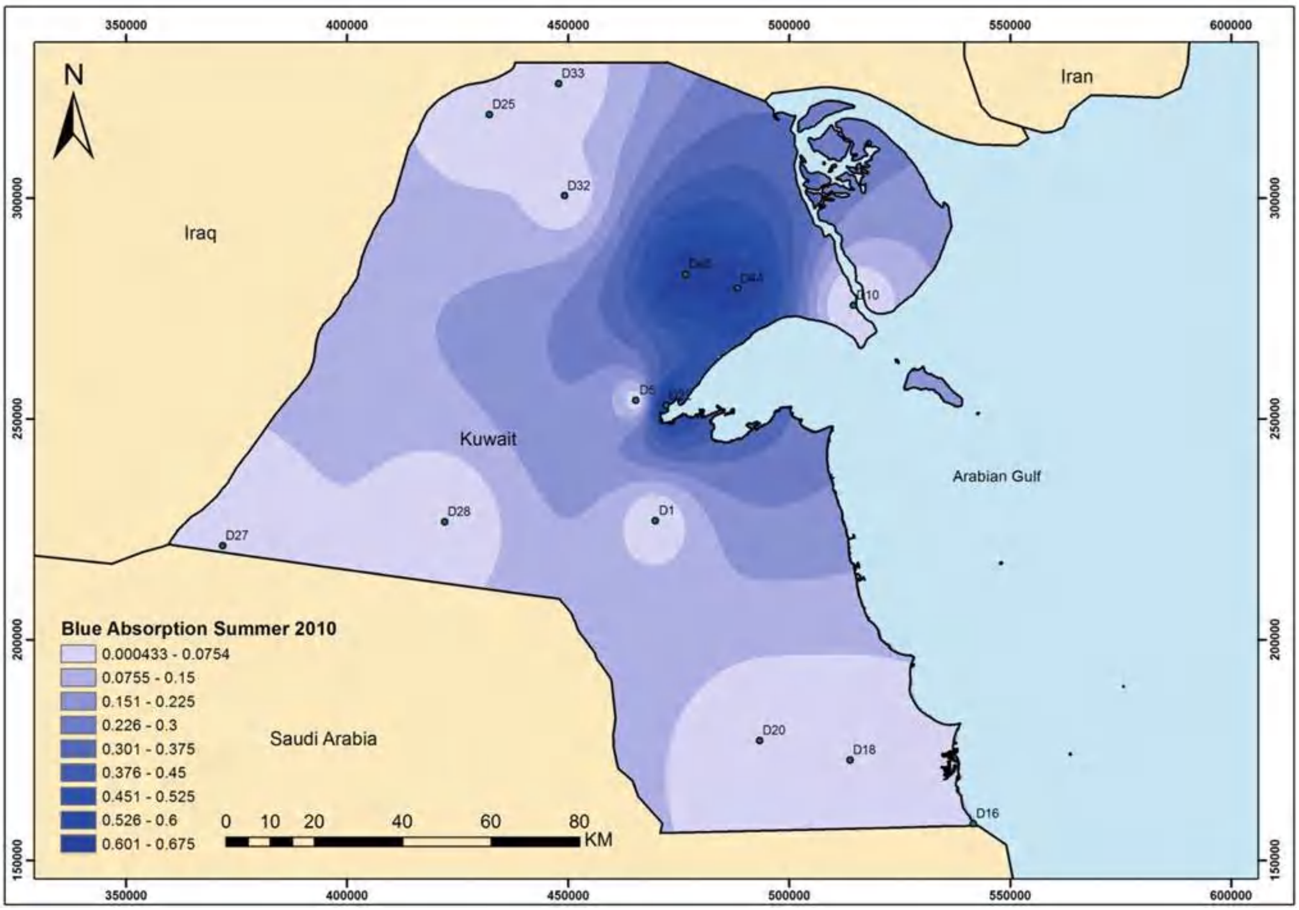

Fig. 9.3 Dust absorption of blue light in summer 2010

Cyan Absorption Summer 2010

The cyan light absorbed in summer varies throughout Kuwait. The dust shows high absorption of cyan light at Sabah Al-Ahmad Natural Reserve (collectors D44 and D45), and it begins to reduce near the coastal side of Kuwait Bay (collector D22 in Kathma). On the border with Iraq, the absorption of cyan light was very low at collector D25 South Buffer zone, D32 Homa, and D33 Ritqa. The same tendency is apparent on the borderline with Saudi Arabia along southeast borders at collector D20 Wafra animal farm, D18 Ras Zur-Wafra, D16 Nuwaissieb, D27 Salmi border zone, and D28 Poultry mid-way Salmi road Abraq. In general, the area near Kuwait Bay, which covers Kuwait City and Hawalli, had a high absorbance of cyan light. The absorbance capacity starts to reduce toward Jahra City in north and Ahmadi in the south. The chemical content of the dust near Kuwait Bay has the ability to absorb more cyan light in the summer than in areas that are farther away (Fig. 9.4).

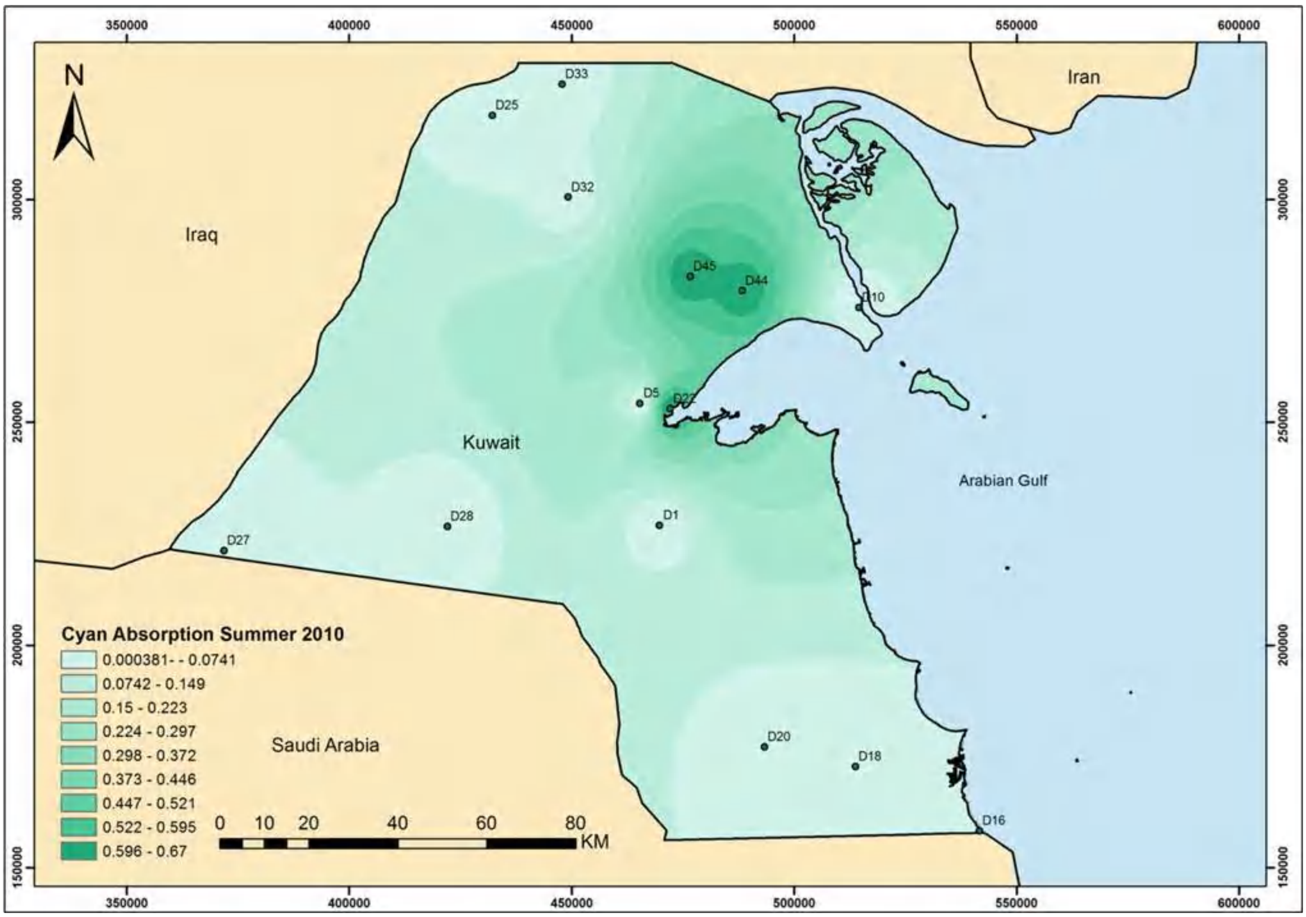

Fig. 9.4 Dust absorption of cyan light in summer 2010

Green Absorption Summer 2010

The green light absorbed in summer varies throughout Kuwait. The dust shows a high absorption of green light at Sabah Al-Ahmad Nature Reserve (collectors D44 and D45) and begins to reduce near the coastal side Kuwait Bay (collector D22 in Kathma). On the border with Iraq, the absorption of green light was very low at collector D25 South Buffer zone, D32 Homa, and D33 Ritqa, as well as on the borderline with Saudi Arabia along the southeast borders at collector D20 Wafra animal farm, D18 Ras Zur-Wafra, D16 Nuwaissieb, D27 Salmi border zone, and D28 Poultry mid-way Salmi road Abraq. In general, the area near Kuwait Bay, which covers Kuwait City and Hawalli, had a high absorbance of green light. The absorbance capacity starts to reduce toward Jahra City in north and Ahmadi in the south. The chemical content of the dust near Kuwait Bay has the ability to absorb more green light in the summer than in areas that are farther away (Fig. 9.5).

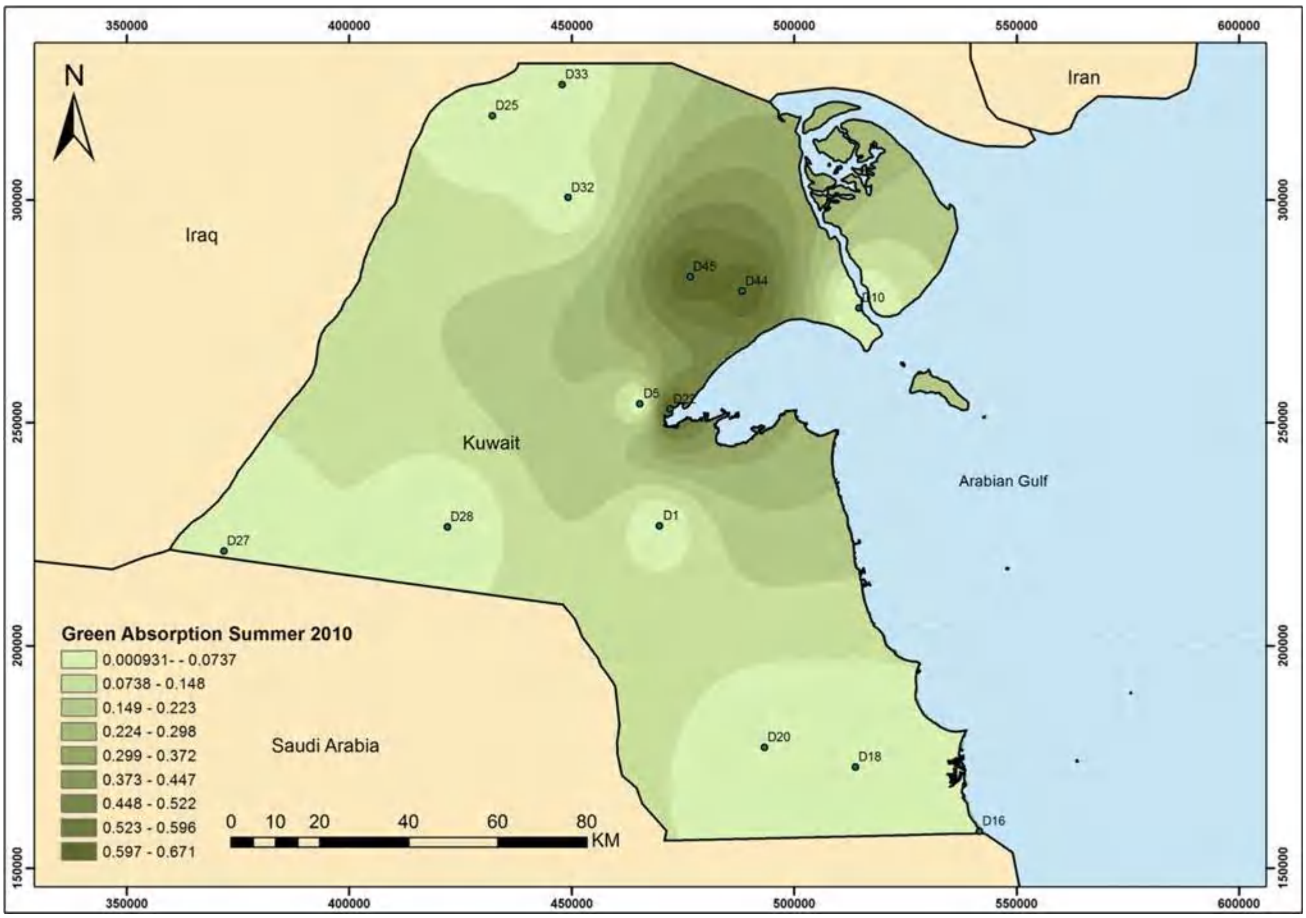

Fig. 9.5 Dust absorption of green light in summer 2010

Yellow Absorption Summer 2010

The yellow light absorbed in summer varies throughout Kuwait. The dust particles show a high absorption of yellow light at Sabah Al-Ahmad Nature Reserve (collectors D44 and D45) that begins to reduce near the coastal side Kuwait Bay (collector D22 in Kathma). On the border with Iraq, the absorption of yellow light was very low at collector D25 South Buffer zone, D32 Homa, and D33 Ritqa, as well as on the borderline with Saudi Arabia along the southeast borders at collector D20 Wafra animal farm, D18 Ras Zur-Wafra, D16 Nuwaissieb, D27 Salmi border zone, D28 Poultry mid-way Salmi road Abraq. In general, the area near Kuwait Bay, which covers Kuwait City and Hawalli, had a high absorbance of yellow light. The absorbance capacity starts to reduce toward Jahra City in north and Ahmadi in the south. The chemical content of the dust near Kuwait Bay has the ability to absorb more yellow light in the summer than in areas that are farther away (Fig. 9.6).

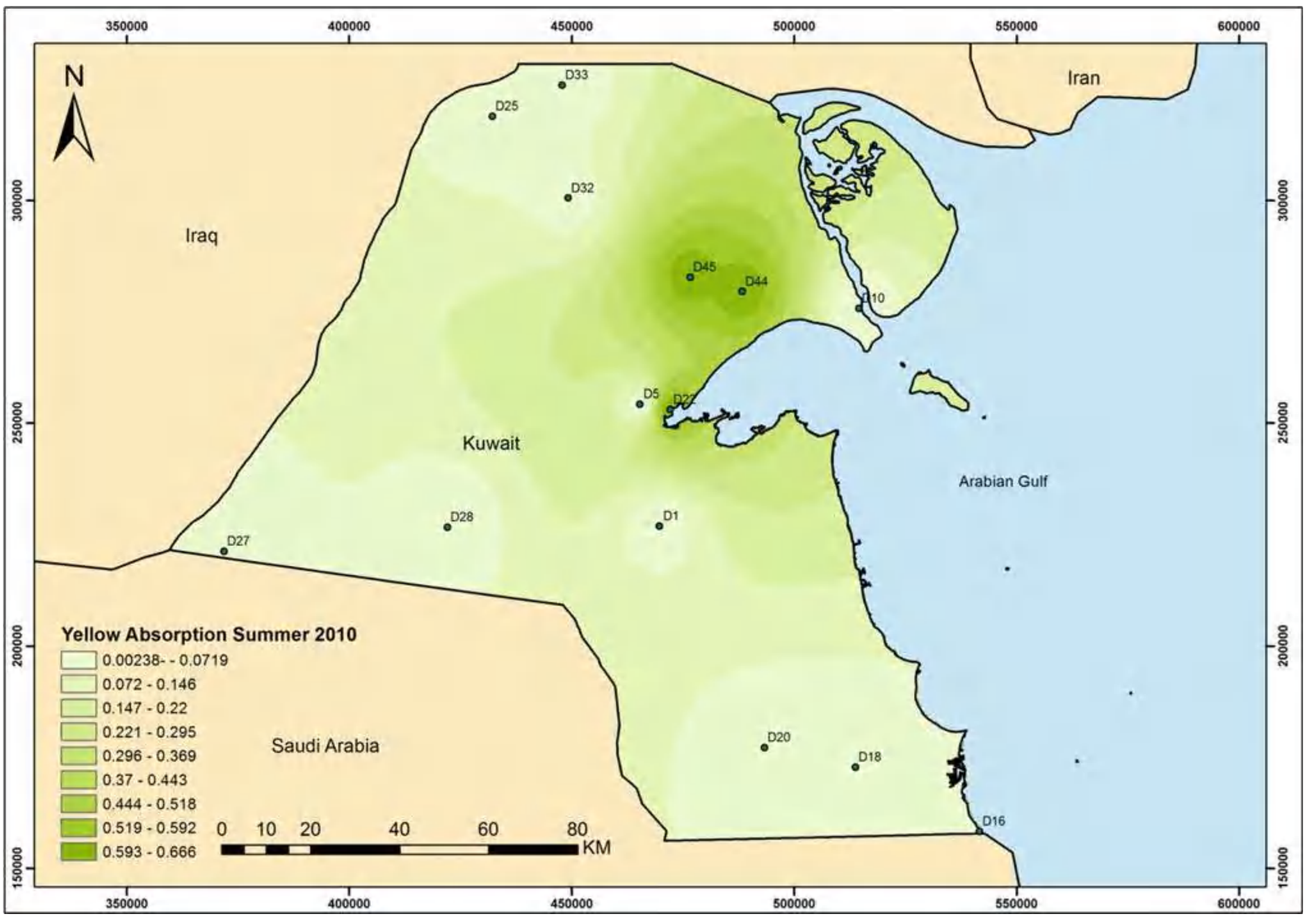

Fig. 9.6 Dust absorption of yellow light in summer 2010

Orange Absorption Summer 2010

The orange light absorbed in summer varies throughout Kuwait. The dust shows high absorption of orange light at Sabah Al-Ahmad Nature Reserve (collectors D44 and D45) and it begins to reduce near the coastal side of Kuwait Bay (collector D22 in Kathma). On the border with Iraq, the absorption of orange light was very low at collector D25 South Buffer zone, D32 Homa, and D33 Ritqa, as well as on the borderline with Saudi Arabia along the southeast borders at collector D20 Wafra animal farm, D18 Ras Zur-Wafra, D16 Nuwaissieb, D27 Salmi border zone, and D28 Poultry mid-way Salmi road Abraq. In general, the area near Kuwait Bay, which covers Kuwait City and Hawalli, had a high absorbance of orange light. The absorbance capacity starts to reduce toward Jahra City in north and Ahmadi in the south. The chemical content of the dust near Kuwait Bay has the ability to absorb more orange light in the summer than in areas that are farther away (Fig. 9.7).

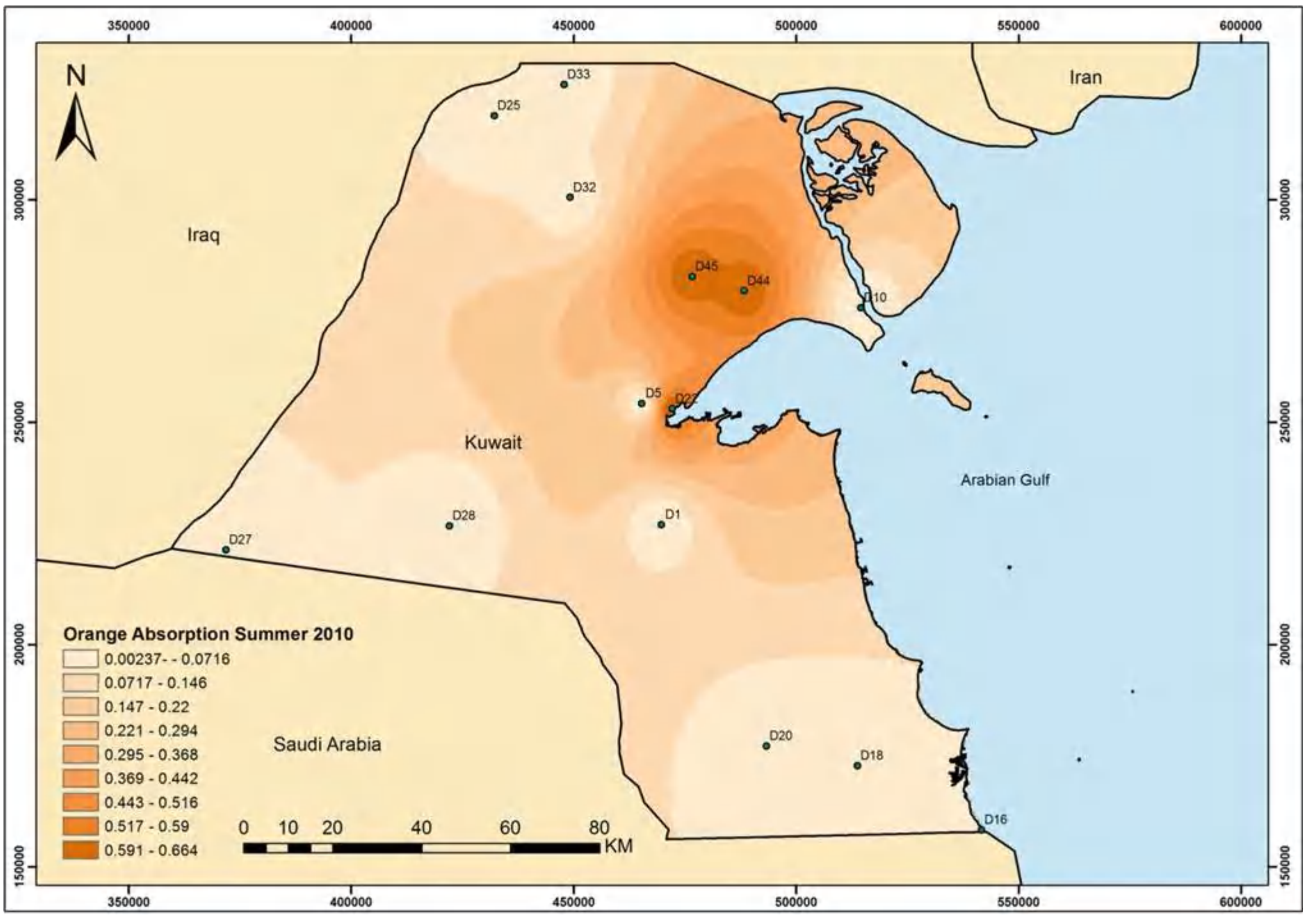

Fig. 9.7 Dust absorption of orange light in summer 2010

Red Absorption Summer 2010

The red light absorbed in summer varies throughout Kuwait. The dust shows high absorption of red light at Sabah Al-Ahmad Nature Reserve (collectors D44 and D45) and begins to reduce near the coastal side Kuwait Bay (collector D22 in Kathma). On the border with Iraq, the absorption of red light was very low at collector D25 South Buffer zone, D32 Homa, and D33 Ritqa, as well as on borderline with Saudi Arabia along the southeast borders at collector D20 Wafra animal farm, D18 Ras Zur-Wafra, D16 Nuwaissieb, D27 Salmi border zone, and D28 Poultry mid-way Salmi road Abraq. In general, the area near Kuwait Bay, which covers Kuwait City and Hawalli, had a high absorbance of red light. The absorbance capacity starts to reduce toward Jahra City in north and Ahmadi in the south. The chemical content of the dust near Kuwait Bay has the ability to absorb more red light in the summer than in areas that are farther away (Fig. 9.8).

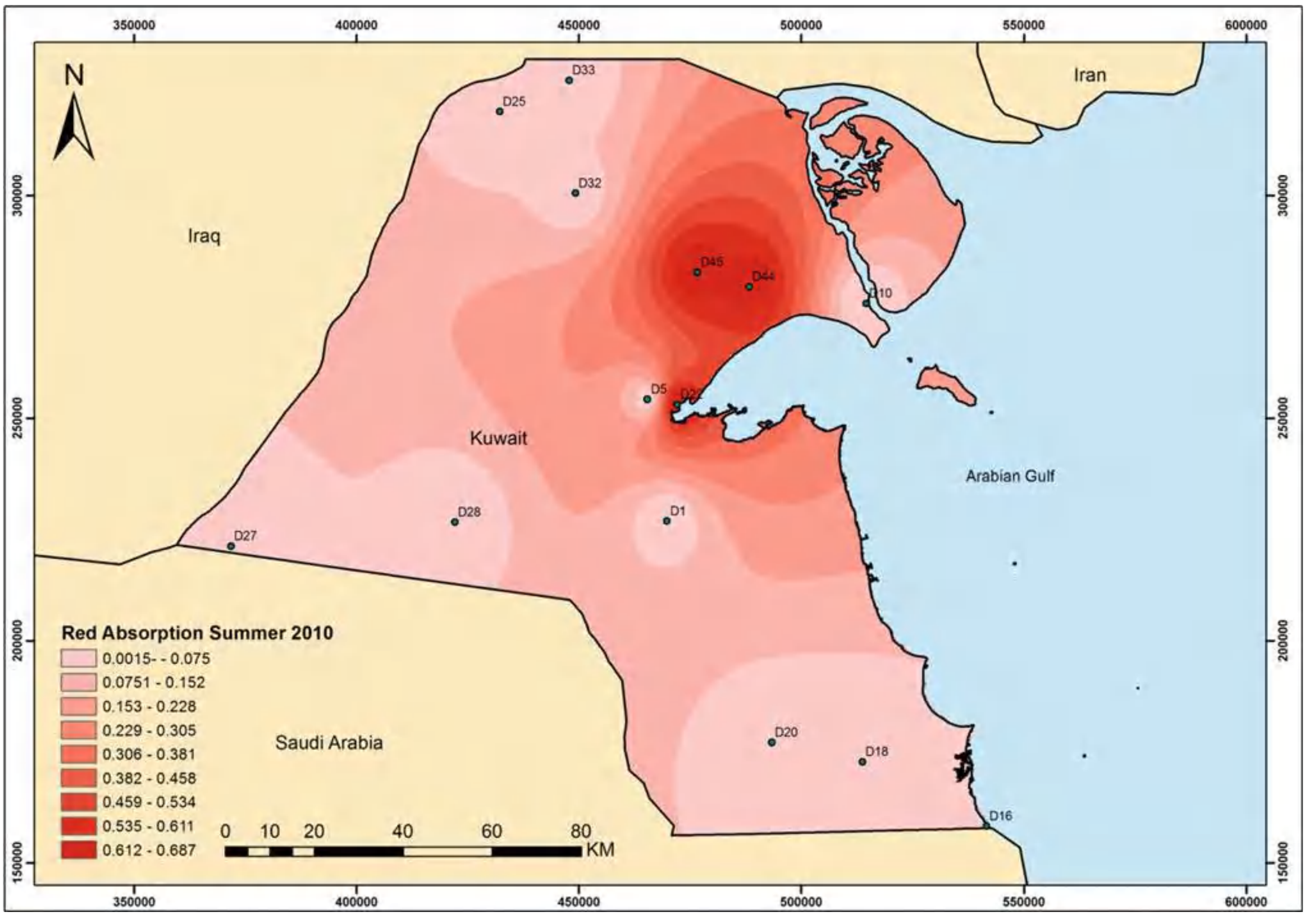

Fig. 9.8 Dust absorption of red light in summer 2010

Infrared Absorption Summer 2010

The absorbed infrared light in summer varies throughout Kuwait. The dust shows high absorption of infrared light at Sabah Al-Ahmad Nature Reserve (collectors D44 and D45) and begins to reduce near the coastal side Kuwait Bay (collector D22 in Kathma). On the border with Iraq, the absorption of infrared light was very low at collector D25 South Buffer zone, D32 Homa, and D33 Ritqa, as well as on the borderline with Saudi Arabia along the southeast borders at collector D20 Wafra animal farm, D18 Ras Zur-Wafra, D16 Nuwaissieb, D27 Salmi border zone, and D28 Poultry mid-way Salmi road Abraq. In general, the area near Kuwait Bay, which covers Kuwait City and Hawalli, had a high absorbance of infrared light. The absorbance capacity starts to reduce toward Jahra City in north and Ahmadi in the south. The chemical content of the dust near Kuwait Bay has the ability to absorb more infrared light in the summer than in areas that are farther away (Fig. 9.9).

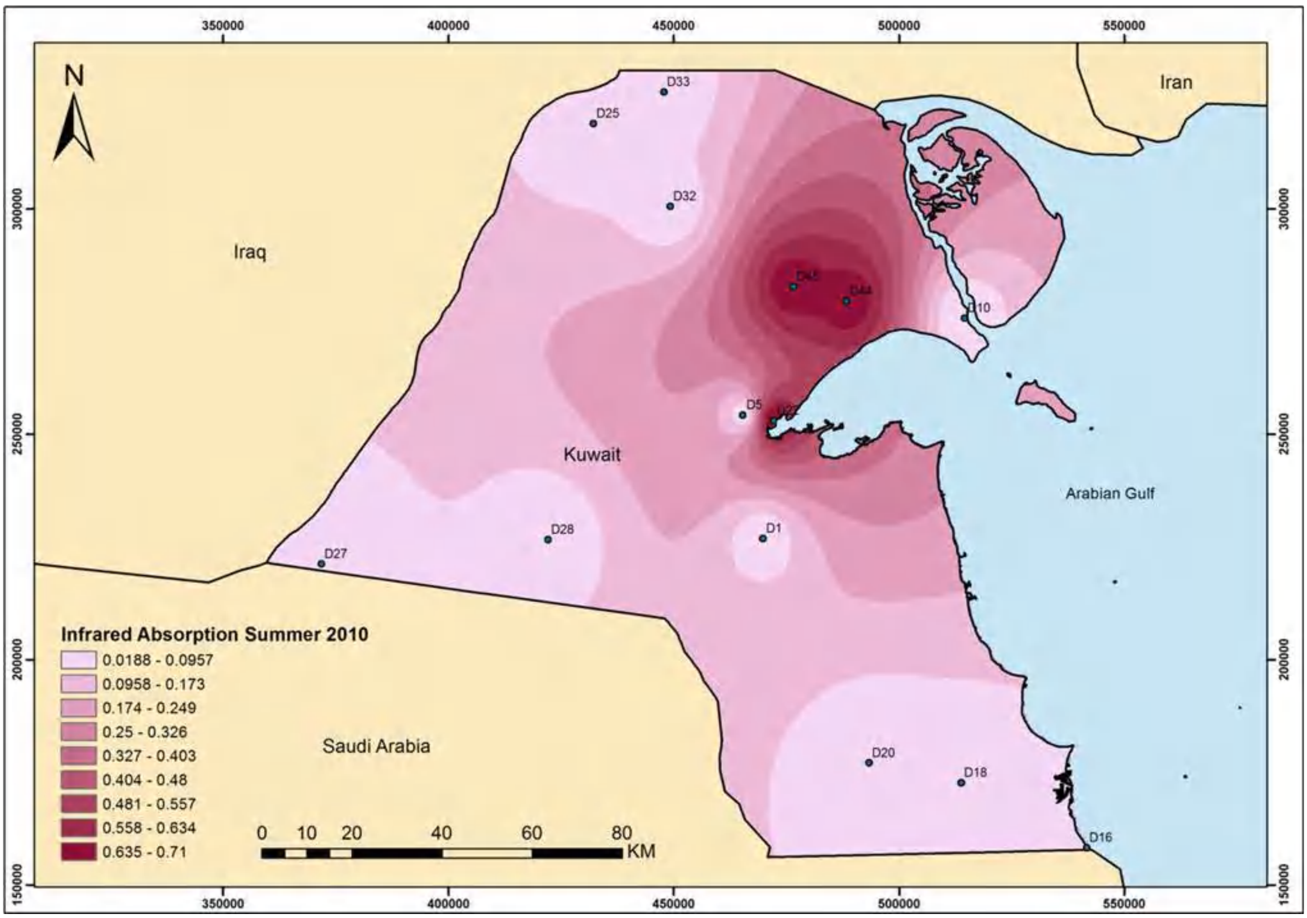

Fig. 9.9 Dust absorption of infrared light in summer 2010

UV Absorption Fall 2010

The ultraviolet light absorbed in autumn varies throughout Kuwait. The dust shows high absorption of ultraviolet light at Sabah Al-Ahmad Nature Reserve (collector D44), at Sabiya close to the Bubiyan bridge (collector D10), near Saudi Arabia at Um Jethathil (collector D41), at Nuwaissieb (collector D16), and at Wafra animal farm (collector D20). The absorption of ultraviolet light was very low at Abdulia-Managish Road (collector D2), at Poultry mid-way Salmi road (collector D28), and at Sabah Al-Ahmad Nature Reserve (collector D42). In fall, the ultraviolet light absorption varies from high to low in Kuwait Bay. The southern borderline with Saudi Arabia (collector D19) and Salmi border zone (collector D27) had medium ultraviolet light absorbance, while the northern part of Kuwait at Ritqa (collector D33) had mid-high absorption (Fig. 9.10).

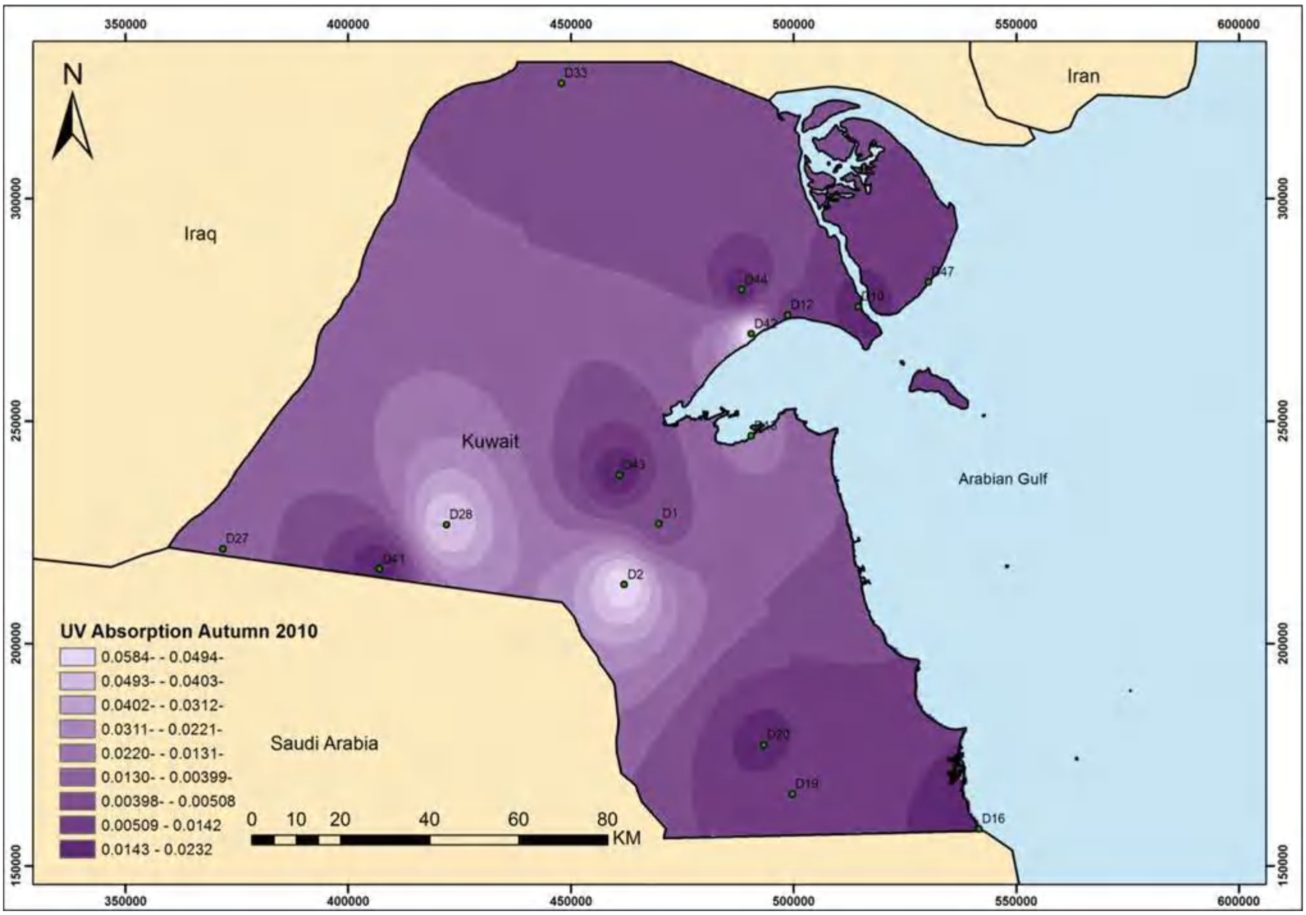

Fig. 9.10 Dust absorption of ultraviolet light in fall 2010

Violet Absorption Fall 2010

The absorbed violet light in fall varies throughout Kuwait. The dust shows high absorption of violet light at Sabah Al-Ahmad Nature Reserve (collector D44), at Sabiya close to the Bubiyan bridge (collector D10), near Saudi Arabia at Um Jethathil (collector D41), at Nuwaissieb (collector D16), and at Wafra animal farm (collector D20). The absorption of the violet light was very low at Abdulia-Managish Road (collector D2), at Poultry mid-way Salmi road (collector D28), and at Sabah Al-Ahmad Nature Reserve (collector D42). The southern borderline with Saudi Arabia (collector D19) and Salmi border zone (collector D27) had medium violet light absorbance, while the northern part of Kuwait at Ritqa (collector D33) had mid-high absorption (Fig. 9.11).

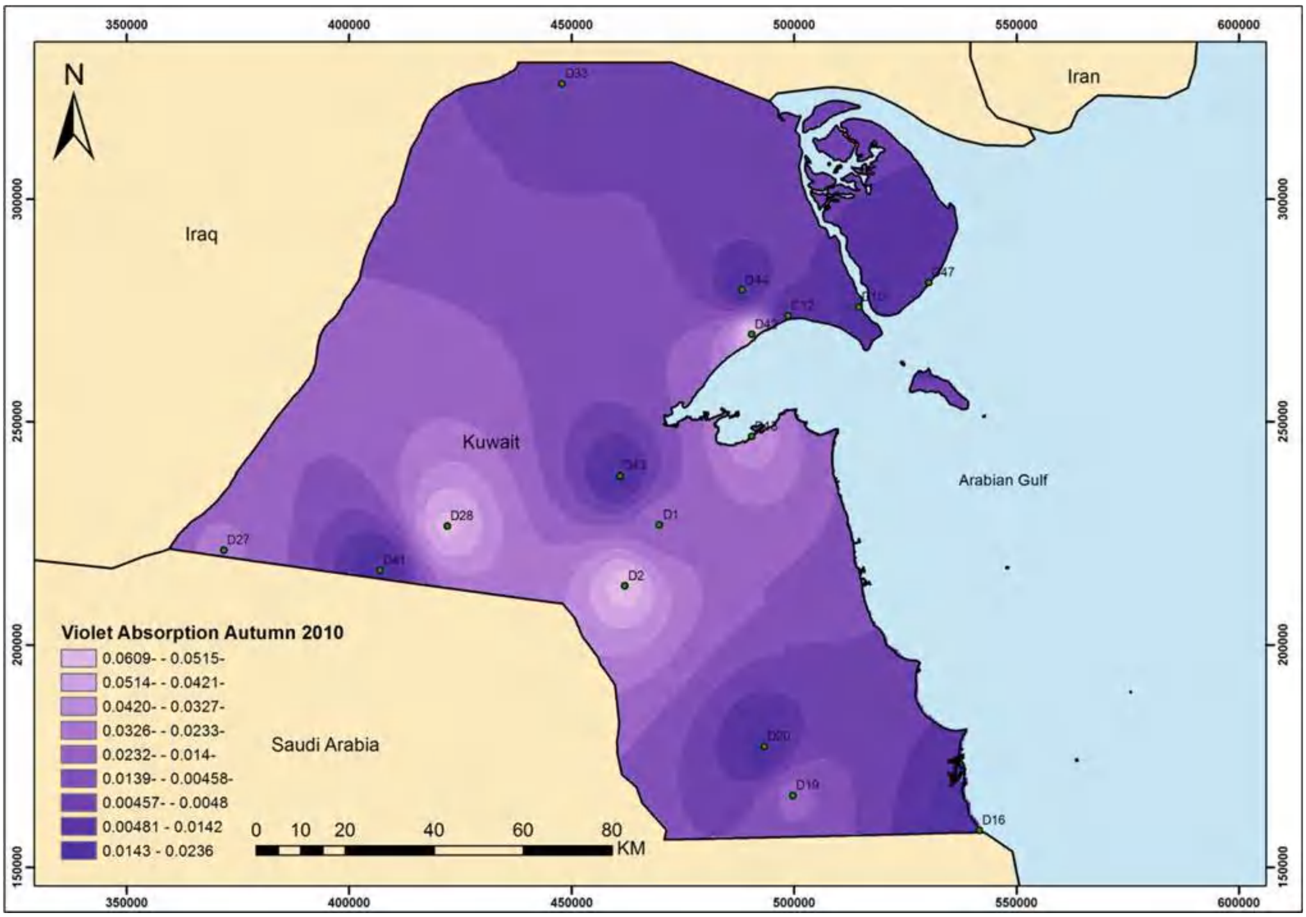

Fig. 9.11 Dust absorption of violet light in fall 2010

Blue Absorption Fall 2010

The blue light absorbed in fall varies throughout Kuwait. The dust shows a high absorption of the blue light at Sabah Al-Ahmad Nature Reserve (collector D44), at Sabiya close to the Bubiyan bridge (collector D10), near Saudi Arabia at Um Jethathil (collector D41), at Nuwaissieb (collector D16), and at Wafra animal farm (collector D20). The absorption of blue light was very low at Abdulia-Managish Road (collector D2), at Poultry mid-way Salmi road (collector D28), and at Sabah Al-Ahmad Nature Reserve (collector D42). In fall, blue light absorption varies from high to low in Kuwait Bay. The southern borderline with Saudi Arabia (collector D19) and Salmi border zone (collector D27) had medium blue light absorbance, while the northern part of Kuwait at Ritqa (collector D33) had mid-high absorption (Fig. 9.12).

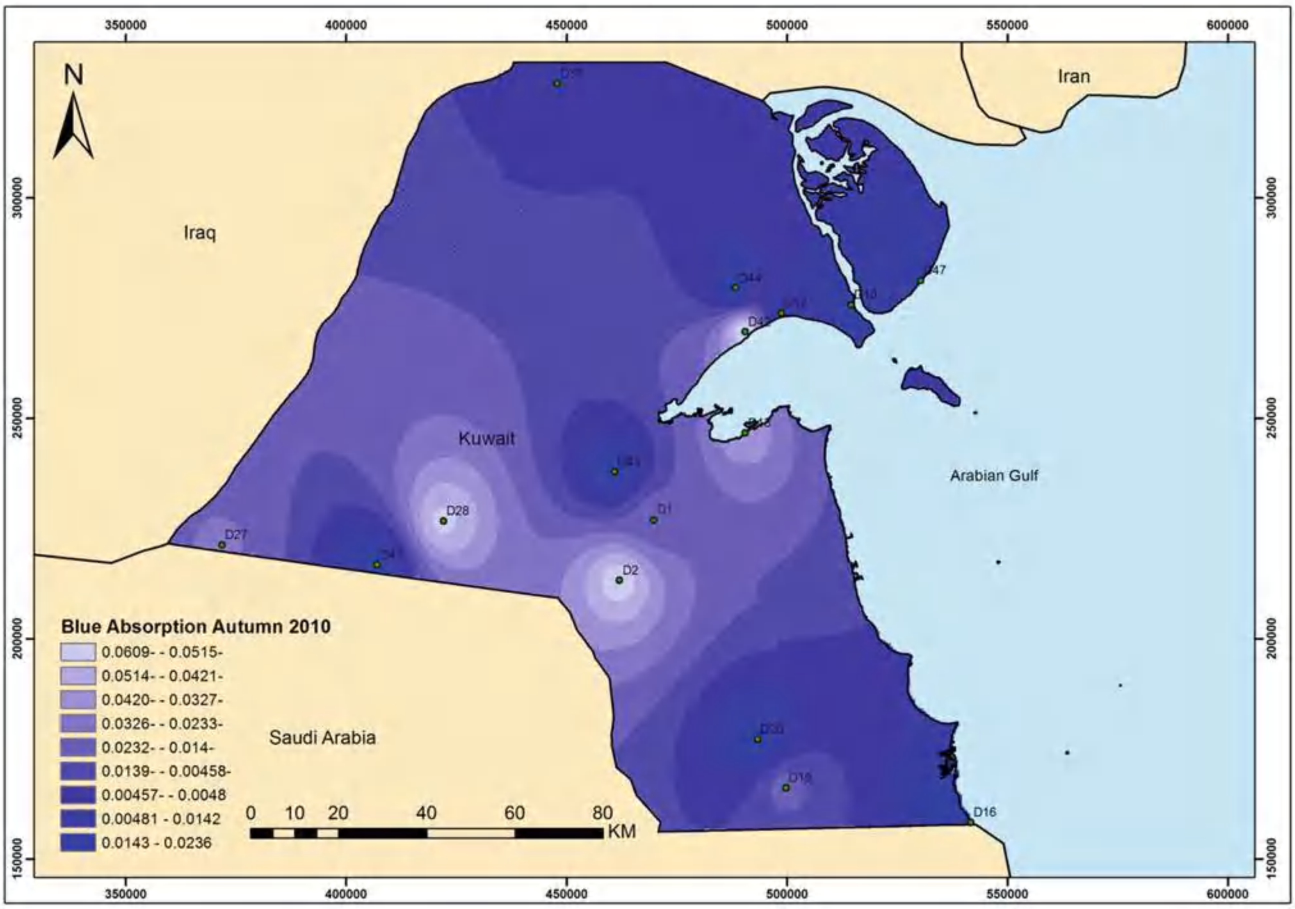

Fig. 9.12 Dust absorption of blue light in fall 2010

Cyan Absorption Fall 2010

The cyan light absorbed in fall varies throughout Kuwait. The dust shows high absorption of cyan light at Sabah Al-Ahmad Nature Reserve (collector D44), at Sabiya close to the Bubiyan bridge (collector D10), near Saudi Arabia at Um Jethathil (collector D41), at Nuwaissieb (collector D16), and at Wafra animal farm (collector D20). The absorption of cyan light was very low at Abdulia-Managish Road (collector D2), at Poultry mid-way Salmi road (collector D28), and at Sabah Al-Ahmad Nature Reserve (collector D42). In fall, cyan light absorption varies from high to low in Kuwait Bay. The southern borderline with Saudi Arabia (collector D19) and Salmi border zone (collector D27) had medium cyan light absorbance, while the northern part of Kuwait at Ritqa (collector D33) had mid-high absorption (Fig. 9.13).

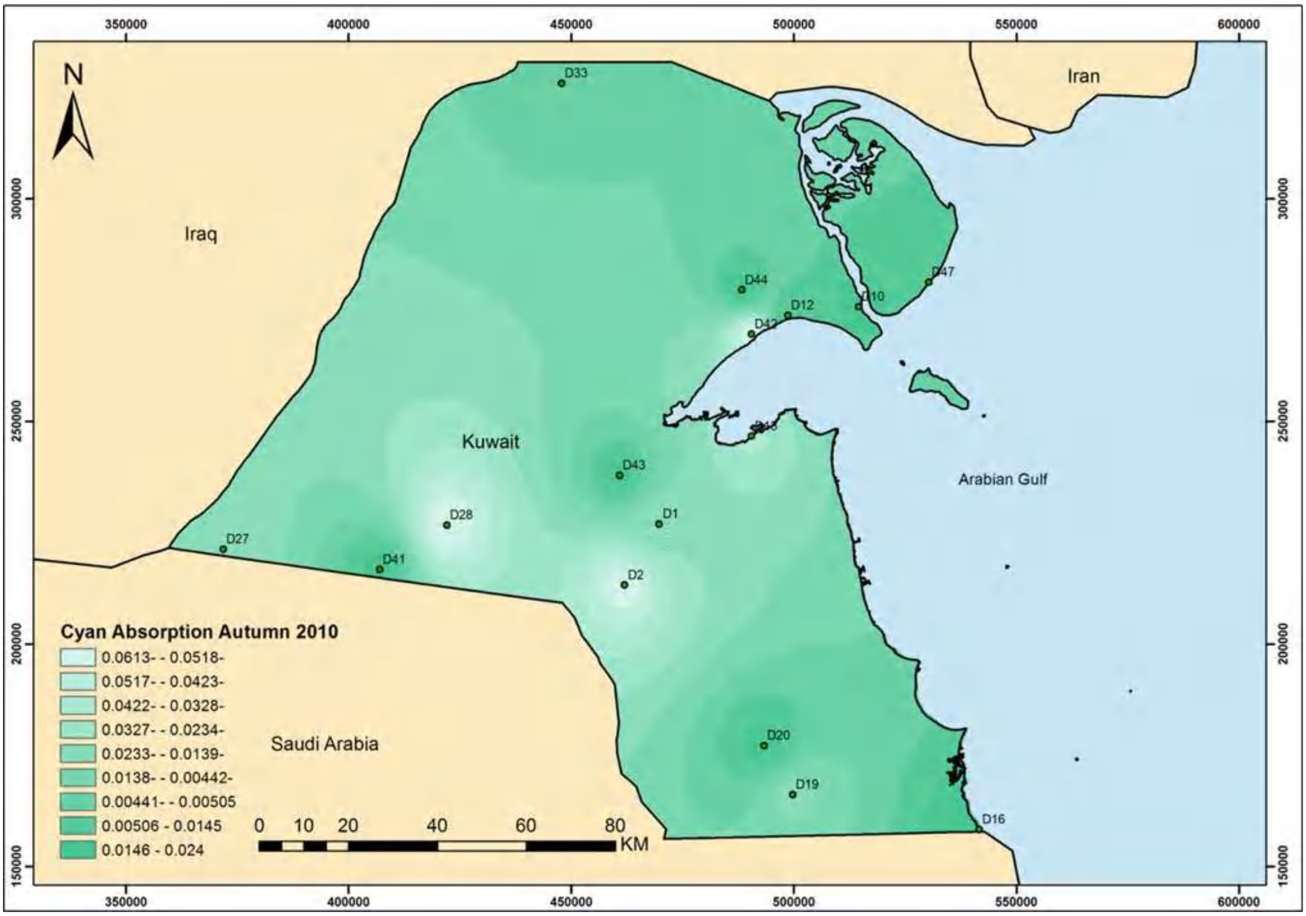

Fig. 9.13 Dust absorption of cyan light in fall 2010

Green Absorption Fall 2010

The green absorbed light in fall varies throughout Kuwait. The dust shows a high absorption of green light at Sabah Al-Ahmad Nature Reserve (collector D44), at Sabiya close to the Bubiyan bridge (collector D10), near Saudi Arabia at Um Jethathil (collector D41), at Nuwaissieb (collector D16), and at Wafra animal farm (collector D20). The absorption of green light was very low at Abdulia-Managish Road (collector D2), at Poultry mid-way Salmi road (collector D28), and at Sabah Al-Ahmad Nature Reserve (collector D42). In fall, green light absorption varies from high to low in Kuwait Bay. The southern borderline with Saudi Arabia (collector D19) and Salmi border zone (collector D27) had medium green light absorbance, while the northern part of Kuwait at Ritqa (collector D33) had mid-high absorption (Fig. 9.14).

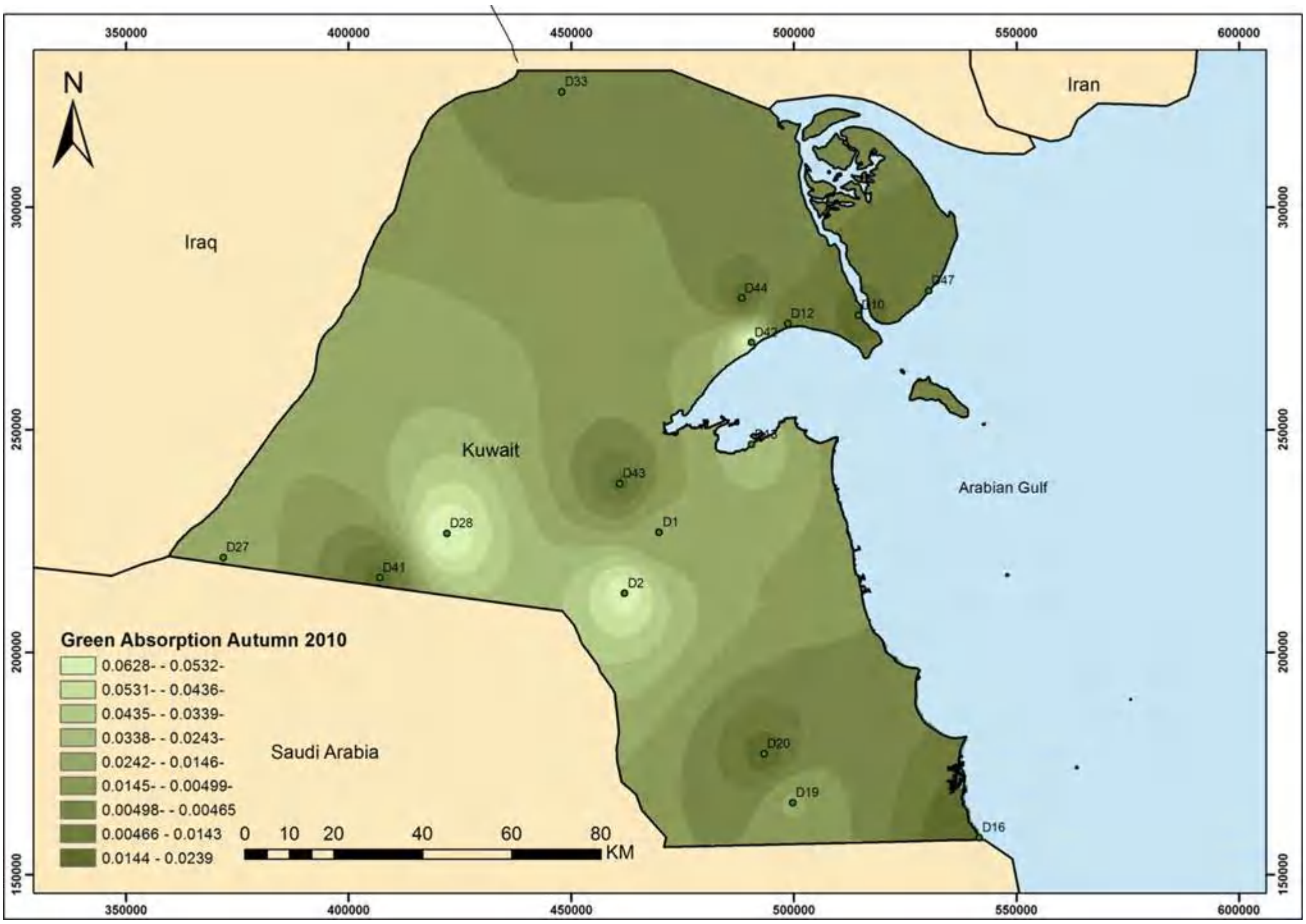

Fig. 9.14 Dust absorption of green light in fall 2010

Yellow Absorption Fall 2010

The yellow light absorbed in fall varies throughout Kuwait. The dust shows a high absorption of yellow light at Sabah Al-Ahmad Nature Reserve (collector D44), at Sabiya (close to the Bubiyan bridge) (collector D10), near Saudi Arabia at Um Jethathil (D41), at Nuwaisssieb (collector D16), and at Wafra animal farm (collector D20). The absorption of yellow light was very low at Abdalia-Managish Road (collector D2), at Poultry mid-way Salmi road (collector D28), and at Sabah Al-Ahmad Nature Reserve (collector D42). In fall, yellow light absorption varies from high to low in Kuwait Bay. The southern borderline with Saudi Arabia (collector D19) and Salmi border zone (collector D27) had medium yellow light absorbance, while the northern part of Kuwait at Ritqa (collector D33) had mid-high absorption (Fig. 9.15).

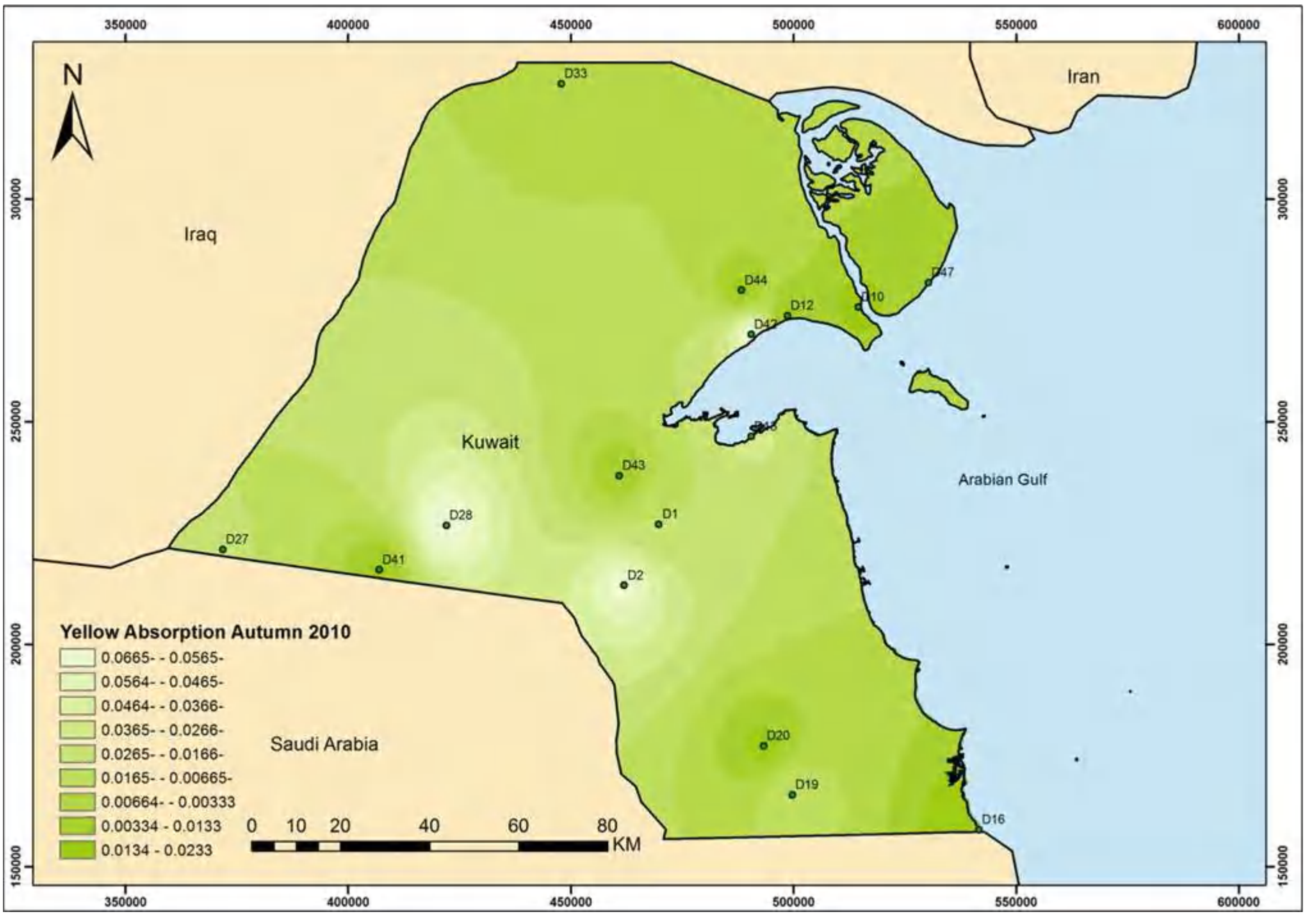

Fig. 9.15 Dust absorption of yellow light in fall 2010

Orange Absorption Fall 2010

The orange light absorbed in fall varies throughout Kuwait. The dust shows high absorption of orange light at Sabah Al-Ahmad Nature Reserve (collector D44), at Sabiya close to the Bubiyan bridge (collector D10), near Saudi Arabia at Um Jethathil (collector D41), at Nuwaissieb (collector D16), and at Wafra animal farm (collector D20). The absorption of orange light was very low at Abdulia-Managish Road (collector D2), at Poultry mid-way Salmi road (collector D28), and at Sabah Al-Ahmad Nature Reserve (collector D42). In fall, orange light absorption varied from high to low in Kuwait Bay. The southern borderline with Saudi Arabia (collector D19) and Salmi border zone (collector D27) had medium orange light absorbance, while the northern part of Kuwait at Ritqa (collector D33) had mid-high absorption (Fig. 9.16).

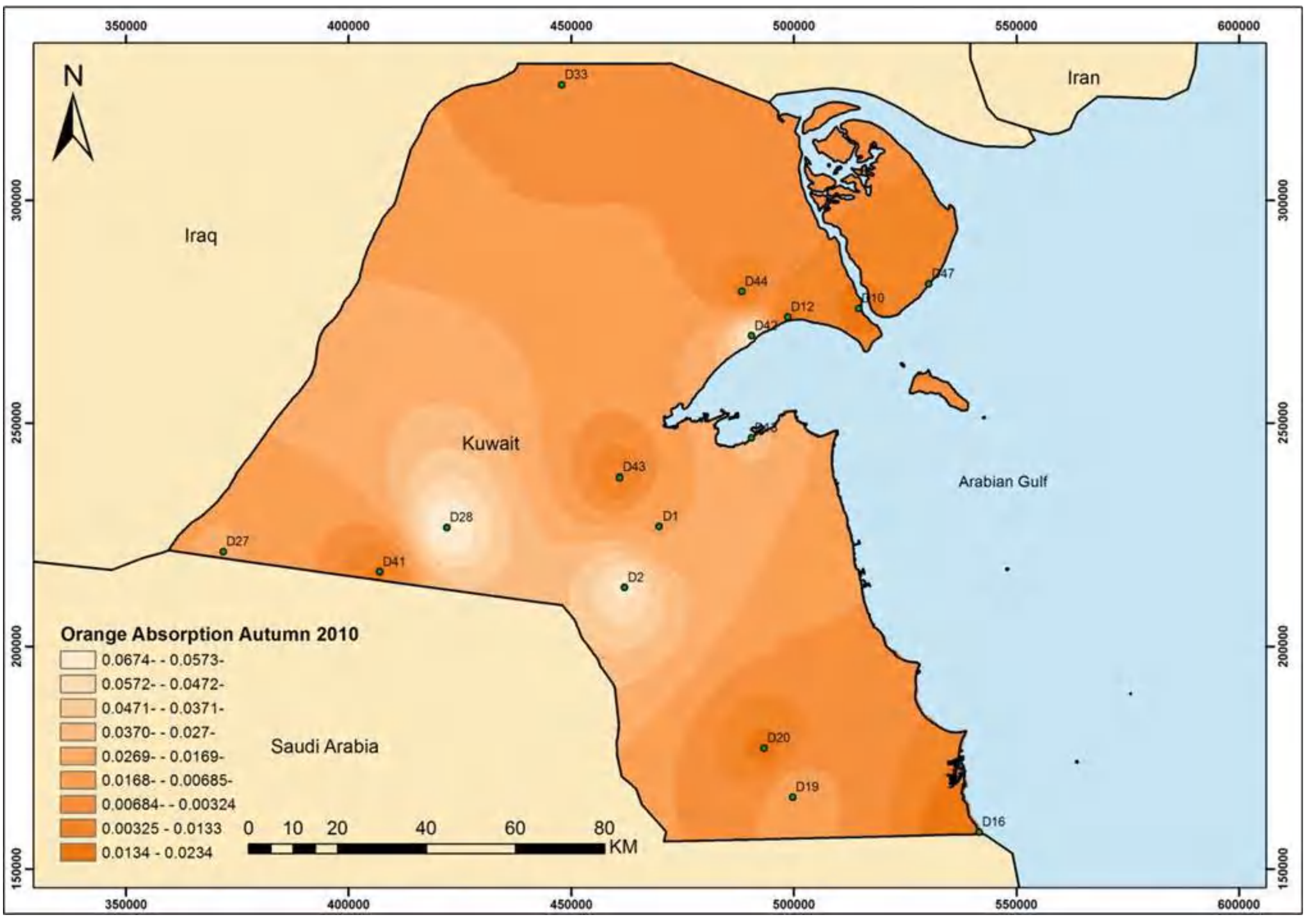

Fig. 9.16 Dust absorption of orange light in fall 2010

Red Absorption Fall 2010

The red light absorbed in fall varies throughout Kuwait. The dust shows high absorption of red light in Sabah Al-Ahmad Nature Reserve (collector D44), at Sabiya close to the Bubiyan bridge (collector D10), near Saudi Arabia at Um Jethathil (collector D41), at Nuwaissieb (collector D16), and at Wafra animal farm (collector D20). The absorption of red light was very low at Abdulia-Managish Road (collector D2), at Poultry mid-way Salmi road (collector D28), and at Sabah Al-Ahmad Nature Reserve (collector D42). In fall, red-light absorption varies from high to low in Kuwait Bay. The southern borderline with Saudi Arabia (collector D19) and Salmi border zone (collector D27) had medium red-light absorbance, while the northern part of Kuwait at Ritqa (collector D33) had mid-high absorption (Fig. 9.17).

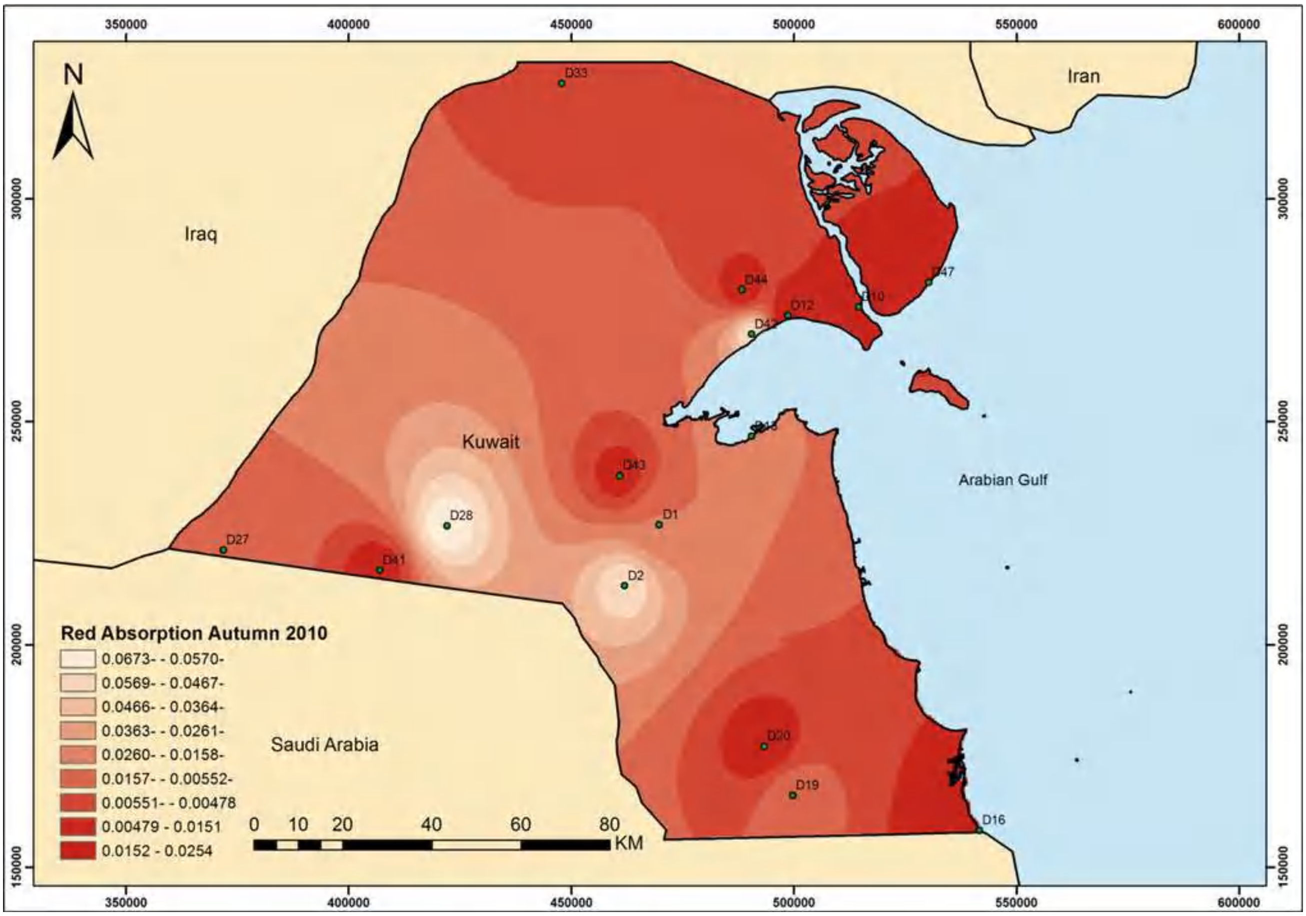

Fig. 9.17 Dust absorption of red light in fall 2010

IR Absorption Fall 2010

The infrared light absorbed in fall varies throughout Kuwait. The dust shows high absorption of infrared light at Sabah Al-Ahmad Nature Reserve (collector D44), at Sabiya close to the Bubiyan bridge (collector D10), near Saudi Arabia at Um Jethathil (collector D41), at Nuwaissieb (collector D16), and at Wafra animal farm (collector D20). The absorption of infrared light was very low at Abdulia-Managish Road (collector D2), at Poultry mid-way Salmi road (collector D28), and at Sabah Al-Ahmad Nature Reserve (collector D42). In fall, infrared light absorption varied from high to low in Kuwait Bay. The southern borderline with Saudi Arabia (collector D19) and Salmi border zone (collector D27) had medium infrared light absorbance, while the northern part of Kuwait at Ritqa (collector D33) had mid-high absorption (Fig. 9.18).

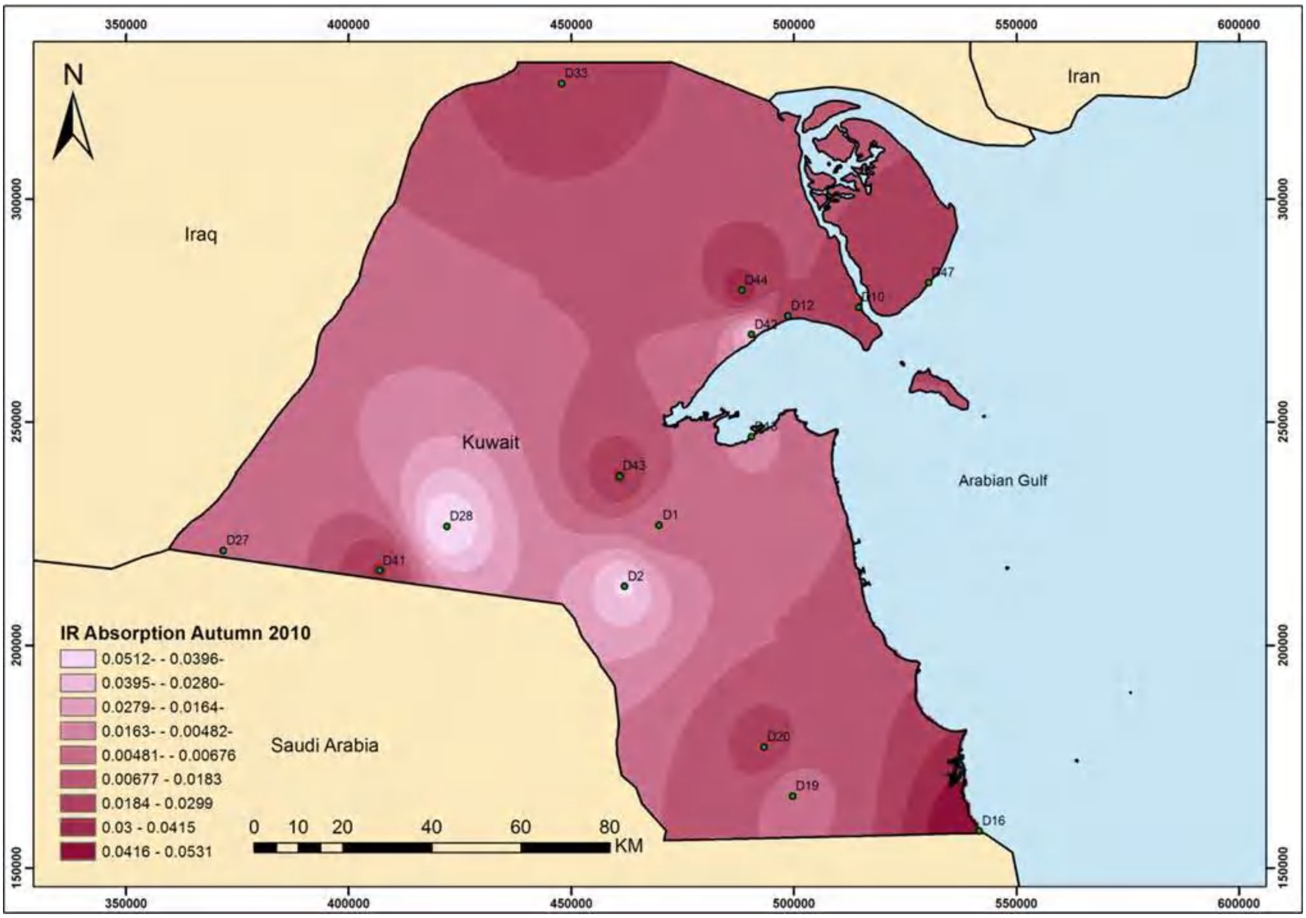

Fig. 9.18 Dust absorption of infrared light in fall 2010

UV Absorption Winter 2010

The absorbed ultraviolet light by dust particles in winter varies throughout Kuwait. The dust shows high absorption of ultraviolet light on the northeastern borders with Saudi Arabia at Abraq (collector D29). The dust shows mid-high absorption of ultraviolet light at various places in Kuwait, including the southern Kuwait-Saudi Arabia border zone (collector D38), as well as on Um Bubiyan Island (collector D46), and the southeast area of Kuwait (collectors 41 and 28). The dust shows medium absorption of ultraviolet light in various places in Kuwait, including Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), in the KISR main building location in Kuwait Bay (collector D13), in Kathma (collector D22), in the northern area in Um Qasir/Bahaith (collector D30), and along the western borders with Saudi Arabia (collector D37). However, the dust shows a low absorption of ultraviolet light in many areas, such as the northern side of Kuwait Bay at Bahra coastal zone (collector D12), in the KISR petroleum center in Ahmadi in the east (collector 15), along the northern borders with Iraq at Ritqa (collector D33), at Homa (collector D32), at gate Sabriya oil field (collector D23), at Kabd station (collector D1), at Abdulia-Managish Road (collector D2), and along the western borders with Saudi Arabia at the Salmi border zone (collector 27) (Fig. 9.19).

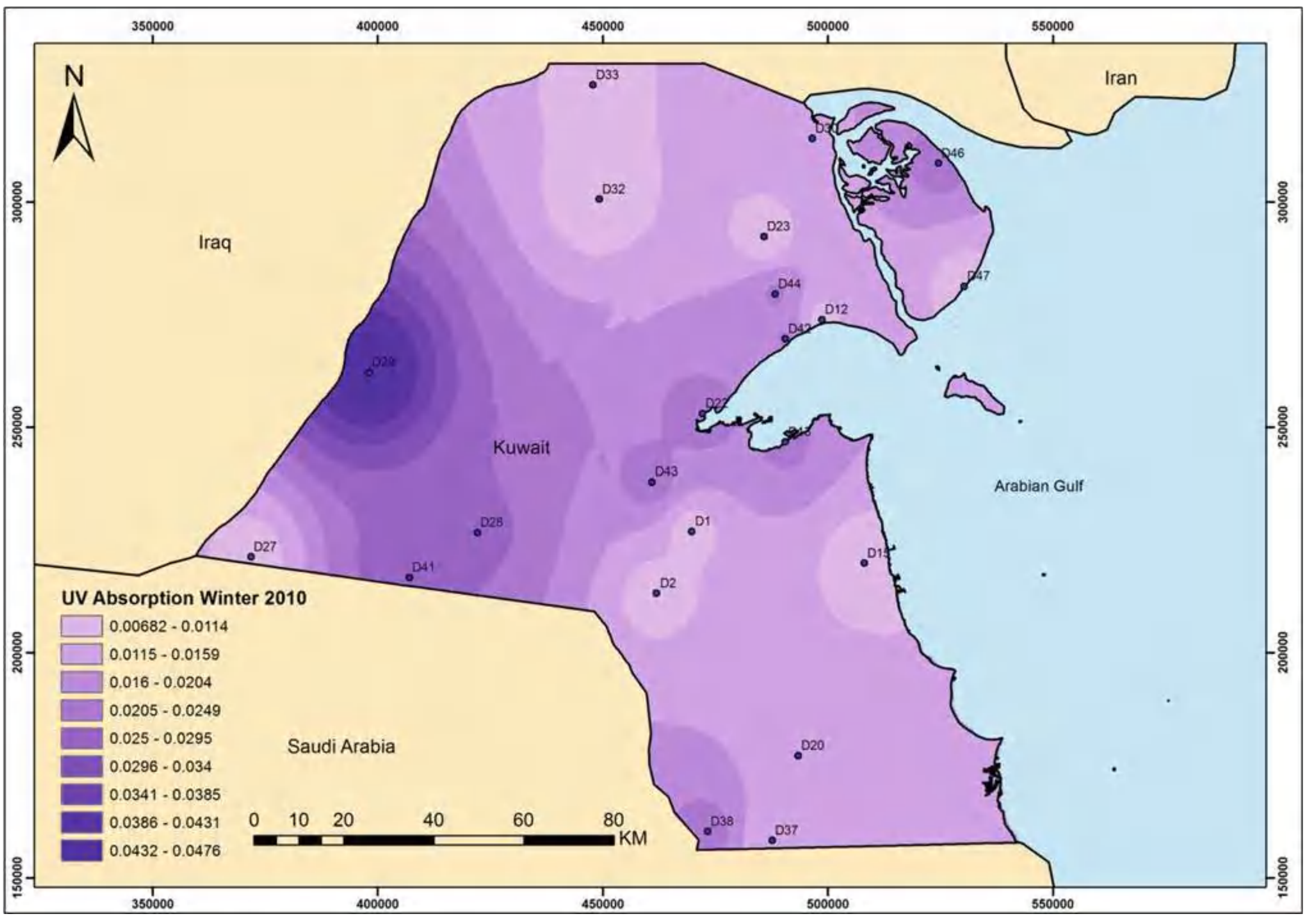

Fig. 9.19 Dust absorption of ultraviolet light in winter 2010

Violet Absorption Winter 2010

The violet light absorbed by dust particles in winter varies throughout Kuwait. The dust shows high absorption of violet light on the northeastern borders with Saudi Arabia at Abraq (collector D29). The dust shows mid-high absorption of violet light at various places in Kuwait, including the southern Kuwait-Saudi Arabia border zone (collector D38), on Bubiyan Island (collector D46), and at the mid-western area of Kuwait (collectors 28 and 41). The dust shows medium absorption of violet light at various places, including Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), in the KISR's main building location in Kuwait Bay (collector D13), in Kathma (collector D22), and in the northern area in Um Qasir/Bahaith (collector D30). However, the dust shows low absorption of violet light in the north of Kuwait Bay at the Bahra coastal zone (collector D12), in the KISR's petroleum center in Ahmadi (collector 15), on the northern borders with Iraq at Ritqa (collector D33), at Homa (collector D32), at gate Sabriya oil field (collector D23), along the western borders with Saudi Arabia (collector D37), at Kabd station (collector D1), at Abdulia-Managish Road (collector D2), and at the western border with Saudi Arabia at Salmi border zone (collector 27) (Fig. 9.20).

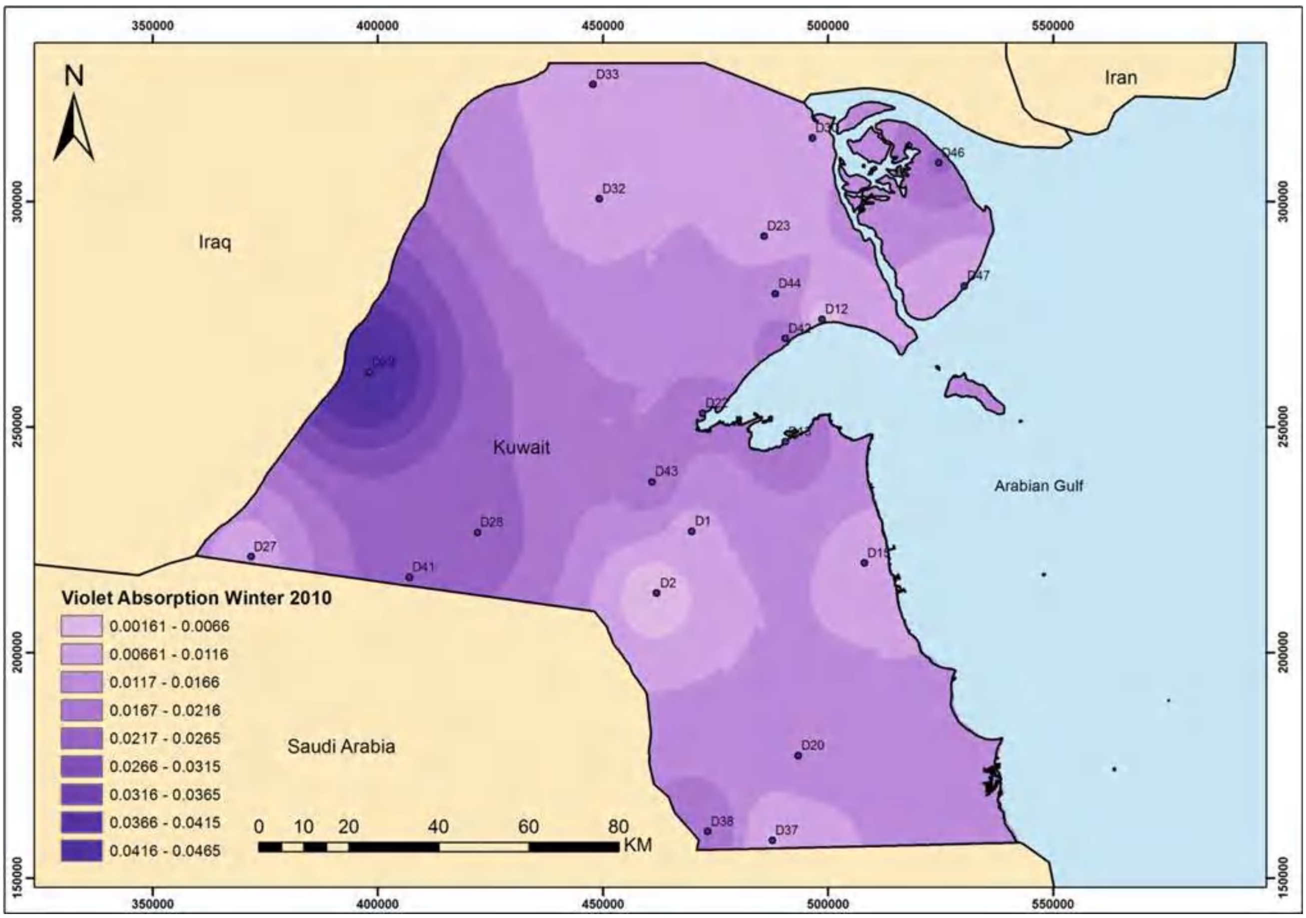

Fig. 9.20 Dust absorption of violet light in winter 2010

Blue Absorption Winter 2010

The blue light absorbed by dust particles in winter varies throughout Kuwait. The dust shows high absorption of blue light on the northeastern border with Saudi Arabia at Abraq (collector D29). The dust shows mid-high absorption of blue light at various places in Kuwait, including the southern Kuwait-Saudi Arabia border zone (collector D38), on Bubiyan Island (collector D46), and at the mid-western area of Kuwait (collectors 28). The dust shows medium absorption of blue light across various places, including Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), in the KISR's main building location in Kuwait Bay (collector D13), in Kathma (collector D22), and in the northern area in Um Qasir/Bahaith (collector D30). However, the dust shows low absorption of blue light in the KISR's petroleum center in Ahmadi (collector 15), on the northern borders with Iraq at Ritqa (collector D33), at Homa (collector D32), at gate Sabriya oil field (collector D23), at Kabd station (collector D1), and at the western borders with Saudi Arabia at Salmi border zone (collector 27). Finally, the dust shows very low absorption at three main areas in Kuwait: north of Kuwait Bay at Bahra coastal zone (collector D12), along the western border with Saudi Arabia (collector D37), and at Abdulia-Managish Road (collector D2) (Fig. 9.21).

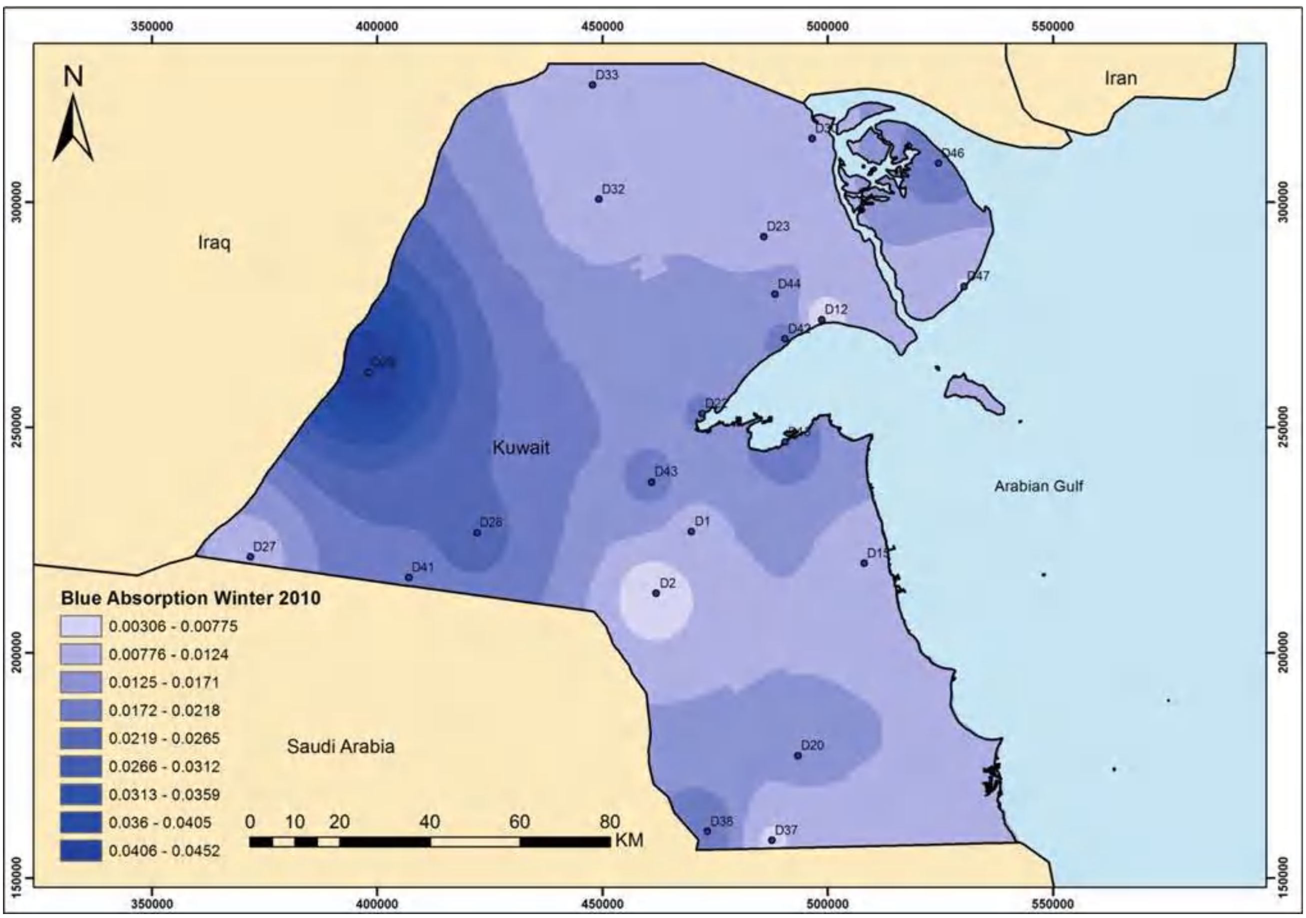

Fig. 9.21 Dust absorption of blue light in winter 2010

Cyan Absorption Winter 2010

The cyan light absorbed by dust particles in winter varies throughout the State of Kuwait. The dust shows high absorption of cyan light on the northeastern border with Saudi Arabia at Abraq (collector D29). The dust shows mid-high absorption of cyan light at various places in Kuwait, including the southern Kuwait-Saudi Arabia border zone (collector D38), on Bubiyan Island (collector D46), and at the mid-western area of Kuwait (collectors 28). The dust shows a medium absorption of cyan light at various other places, including Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), at the KISR's main building location in Kuwait Bay (collector D13), in Kathma (collector D22), and in the northern area in Um Qasir/Bahaith (collector D30). However, the dust shows low absorption of cyan light in the KISR's petroleum center in Ahmadi (collector 15), on the northern border with Iraq at Ritqa (collector D33), at Homa (collector D32), at gate Sabriya oil field (collector D23), at Kabd station (collector D1), and at the western border with Saudi Arabia at Salmi border zone (collector 27). The dust shows very low absorption at three main locations in Kuwait: north of Kuwait Bay at Bahra coastal zone (collector D12), on the western border with Saudi Arabia (collector D37), and at Abdulia-Managish Road (collector D2) (Fig. 9.22).

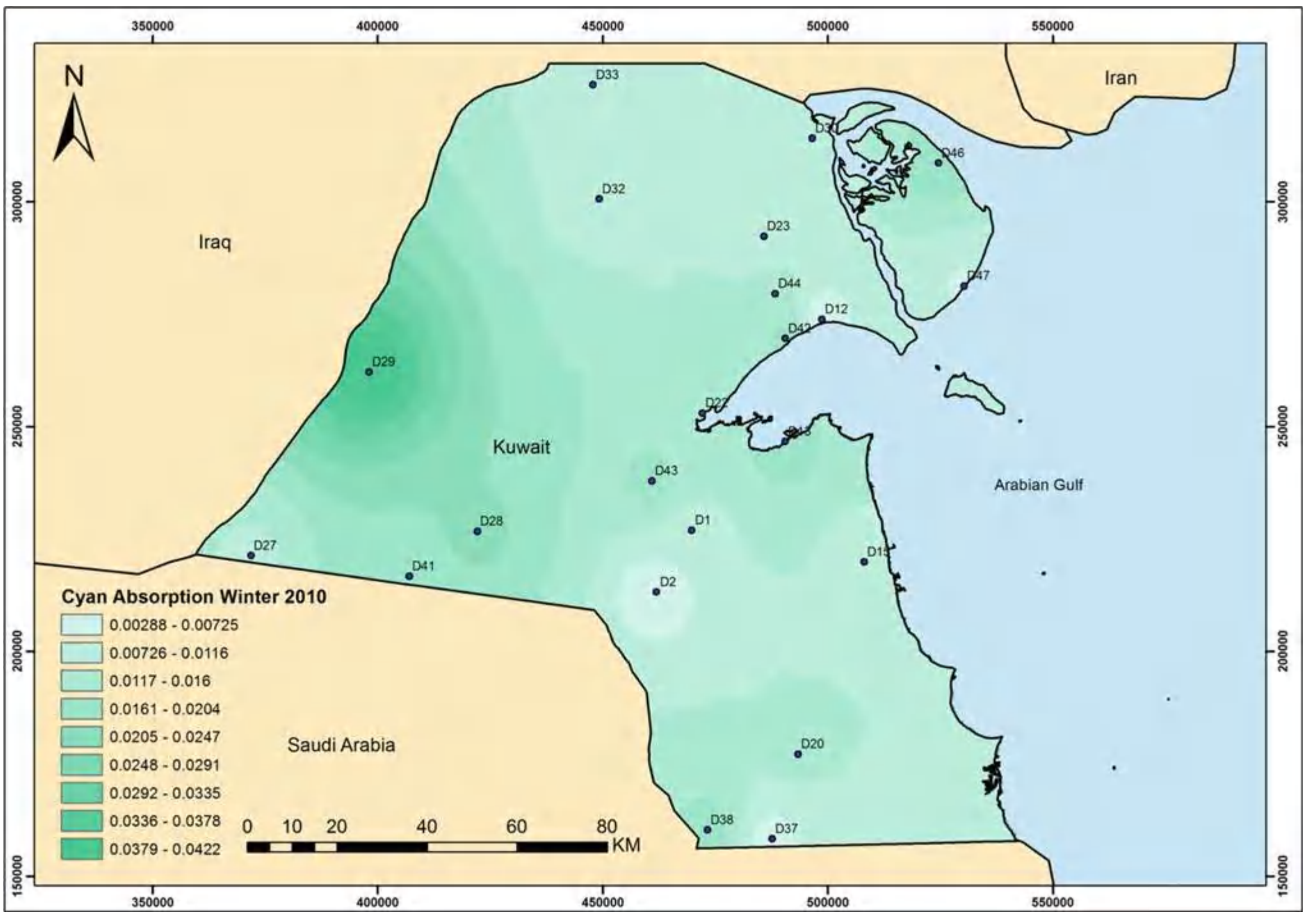

Fig. 9.22 Dust absorption of cyan light in winter 2010

Green Absorption Winter 2010

The green light absorbed by dust particles in winter varies throughout the State of Kuwait. The dust shows high absorption of green light on the northeastern border with Saudi Arabia at Abraq (collector D29). The dust shows mid-high absorption of green light at various places in Kuwait, including the southern Kuwait-Saudi Arabia border zone (collector D38), on Bubiyan Island (collector D46), and at the mid-western area of Kuwait (collectors 28). The dust shows medium absorption of green light at various other places, including Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), at the KISR's main building location in Kuwait Bay (collector D13), in Kathma (collector D22), and in the northern area in Um Qasir/Bahaith (collector D30). However, the dust shows a low absorption of green light in the KISR's petroleum center in Ahmadi (collector 15), on the northern border with Iraq at Ritqa (collector D33), at Homa (collector D32), at gate Sabriya oil field (collector D23), and at Kabd station (collector D1). The dust shows very low absorption of green light across four main locations in Kuwait: north of Kuwait Bay at Bahra coastal zone (collector D12), on the western border with Saudi Arabia (collector D37), at Abdulia-Managish Road (collector D2), and at the western border with Saudi Arabia at Salmi border zone (collector 27) (Fig. 9.23).

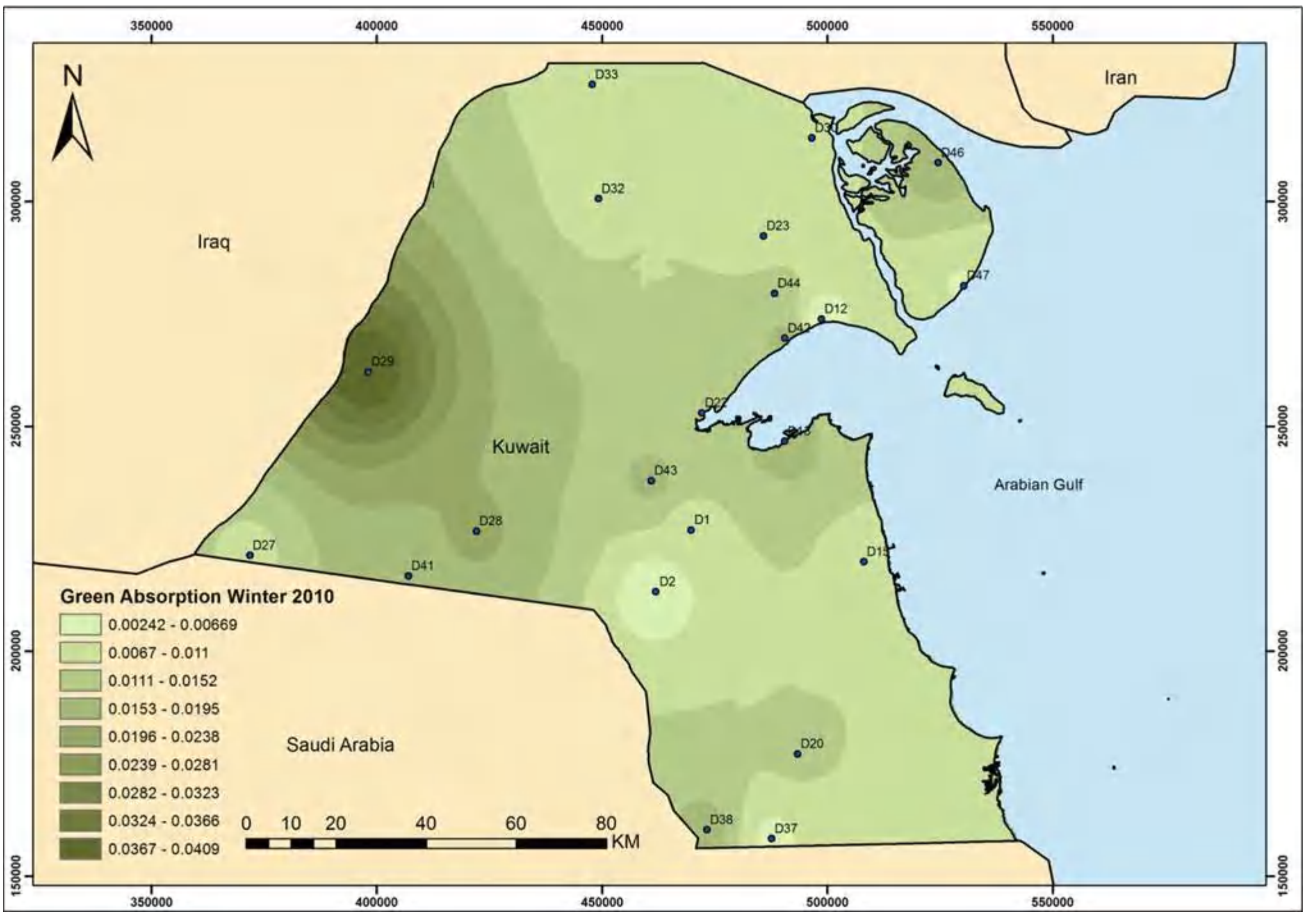

Fig. 9.23 Dust absorption of green light in winter 2010

Yellow Absorption Winter 2010

The yellow light absorbed by dust particles in winter varies throughout Kuwait. The dust shows high absorption of yellow light on the northeastern border with Saudi Arabia at Abraq (collector D29). The dust shows mid-high absorption of yellow light at various places in Kuwait, including the southern Kuwait-Saudi Arabia border zone (collector D38), on Bubiyan Island (collector D46), and at the mid-western area of Kuwait (collectors 28). The dust shows medium absorption of yellow light at various other places, including Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), in the KISR's main building location in Kuwait Bay (collector D13), in Kathma (collector D22), and in the northern area in Um Qasir/Bahaith (collector D30). However, the dust shows low absorption of yellow light in the KISR's petroleum center in Ahmadi (collector 15), on the northern border with Iraq at Ritqa (collector D33), at Homa (collector D32), at gate Sabriya oil field (collector D23), and at Kabd station (collector D1). The dust shows very low absorption of yellow light at four main locations in Kuwait: north of Kuwait Bay at Bahra coastal zone (collector D12), on the western border with Saudi Arabia (collector D37), at Abdulia-Managish Road (collector D2), and on the western border with Saudi Arabia at Salmi border zone (collector 27) (Fig. 9.24).

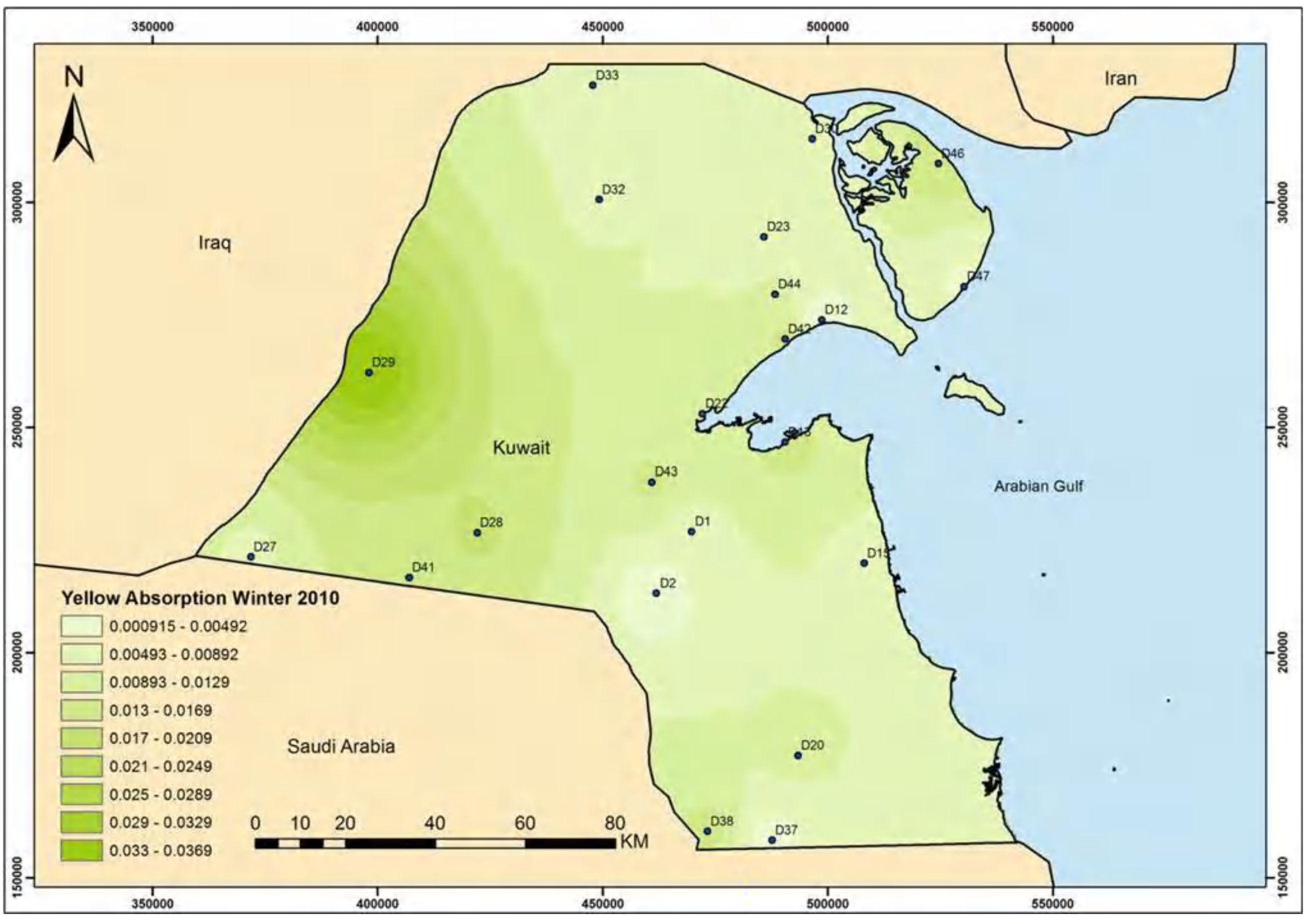

Fig. 9.24 Dust absorption of yellow light in winter 2010

Orange Absorption Winter 2010

The orange light absorbed by dust particles in winter varies throughout the State of Kuwait. The dust shows high absorption of orange light on the northeastern border with Saudi Arabia at Abraq (collector D29). The dust shows mid-high absorption of orange light at various places in Kuwait, including the southern Kuwait-Saudi Arabia border zone (collector D38), on Bubiyan Island (collector D46), and at the mid-western area of Kuwait (collectors 28). The dust shows medium absorption of orange light at various other places, including Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), in the KISR's main building location in Kuwait Bay (collector D13), in Kathma (collector D22), and in the northern area in Um Qasir/Bahaith (collector D30). However, dust shows low absorption of orange light in the KISR's petroleum center in Ahmadi (collector 15), on the northern border with Iraq at Ritqa (collector D33), at Homa (collector D32), at gate Sabriya oil field (collector D23), and at Kabd station (collector D1). The dust shows very low absorption of orange light across four main locations in Kuwait: north of Kuwait Bay at Bahra coastal zone (collector D12), in the western border with Saudi Arabia (collector D37), at Abdulia-Managish Road (collector D2), and on Bubyan Island (collector 47) (Fig. 9.25).

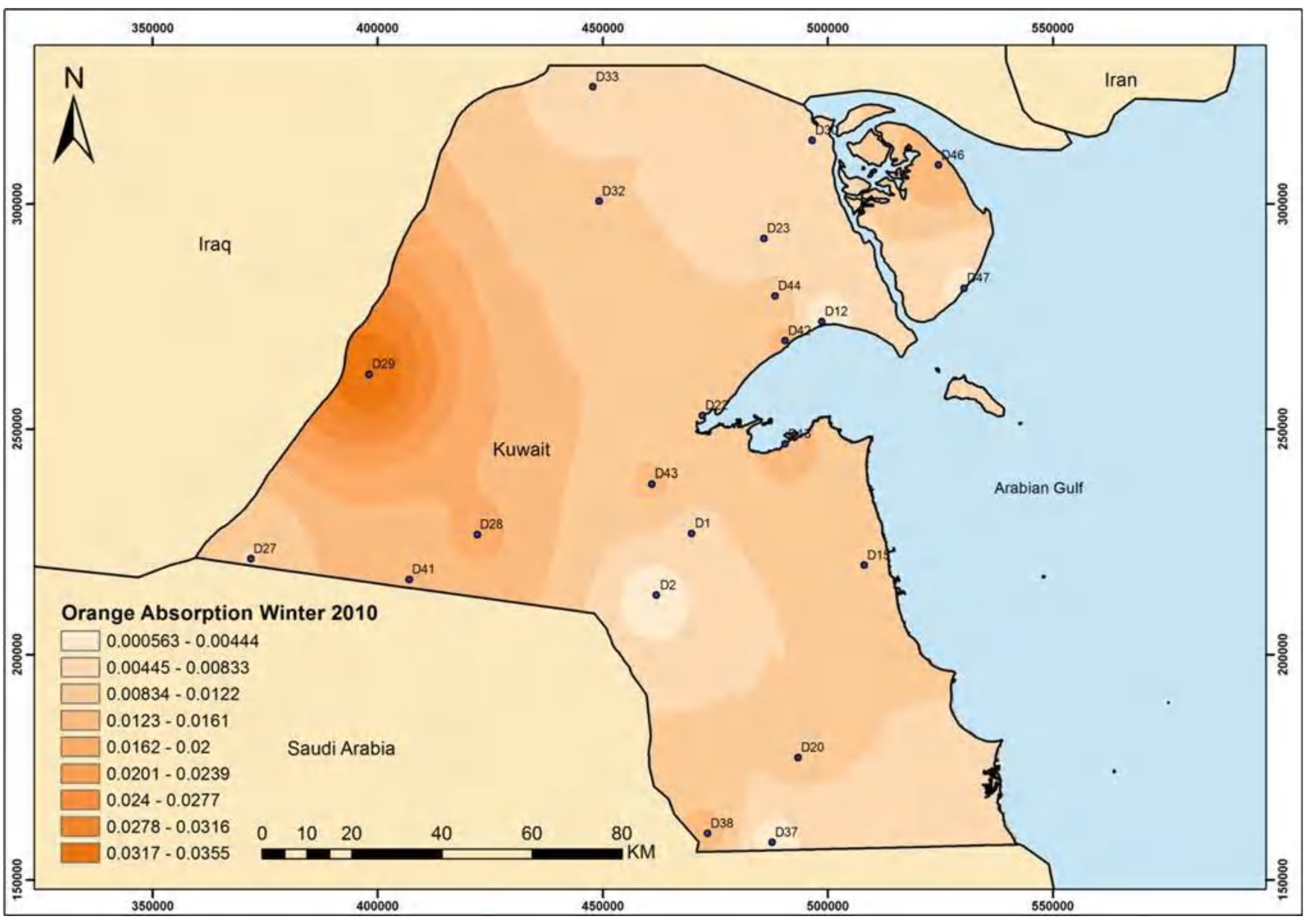

Fig. 9.25 Dust absorption of orange light in winter 2010

Red Absorption Winter 2010

The red light absorbed by dust particles in winter varies throughout Kuwait. The dust shows high absorption of red light on the northeastern border with Saudi Arabia at Abraq (collector D29). The dust shows mid-high absorption of red light across various places of Kuwait, including the southern Kuwait-Saudi Arabia border zone (collector D38), on Bubiyan Island (collector D46), and at the mid-western area of Kuwait (collectors 28). The dust shows medium absorption of red light across various other places, including Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), in the KISR's main building location in Kuwait Bay (collector D13), in Kathma (collector D22), and in the northern area in Um Qasir/Bahaith (collector D30). However, the dust shows a low absorption of red light at the KISR's petroleum center in Ahmadi (collector 15), on the northern border with Iraq at Ritqa (collector D33), at Homa (collector D32), at gate Sabriya oil field (collector D23), and at Kabd station (collector D1). The dust shows very low absorption of red light across four main locations in Kuwait: north of Kuwait Bay at Bahra coastal zone (collector D12), on the western border with Saudi Arabia (collector D37), at Abdulia-Managish Road (collector D2), and on Bubiyan Island (collector 47) (Fig. 9.26).

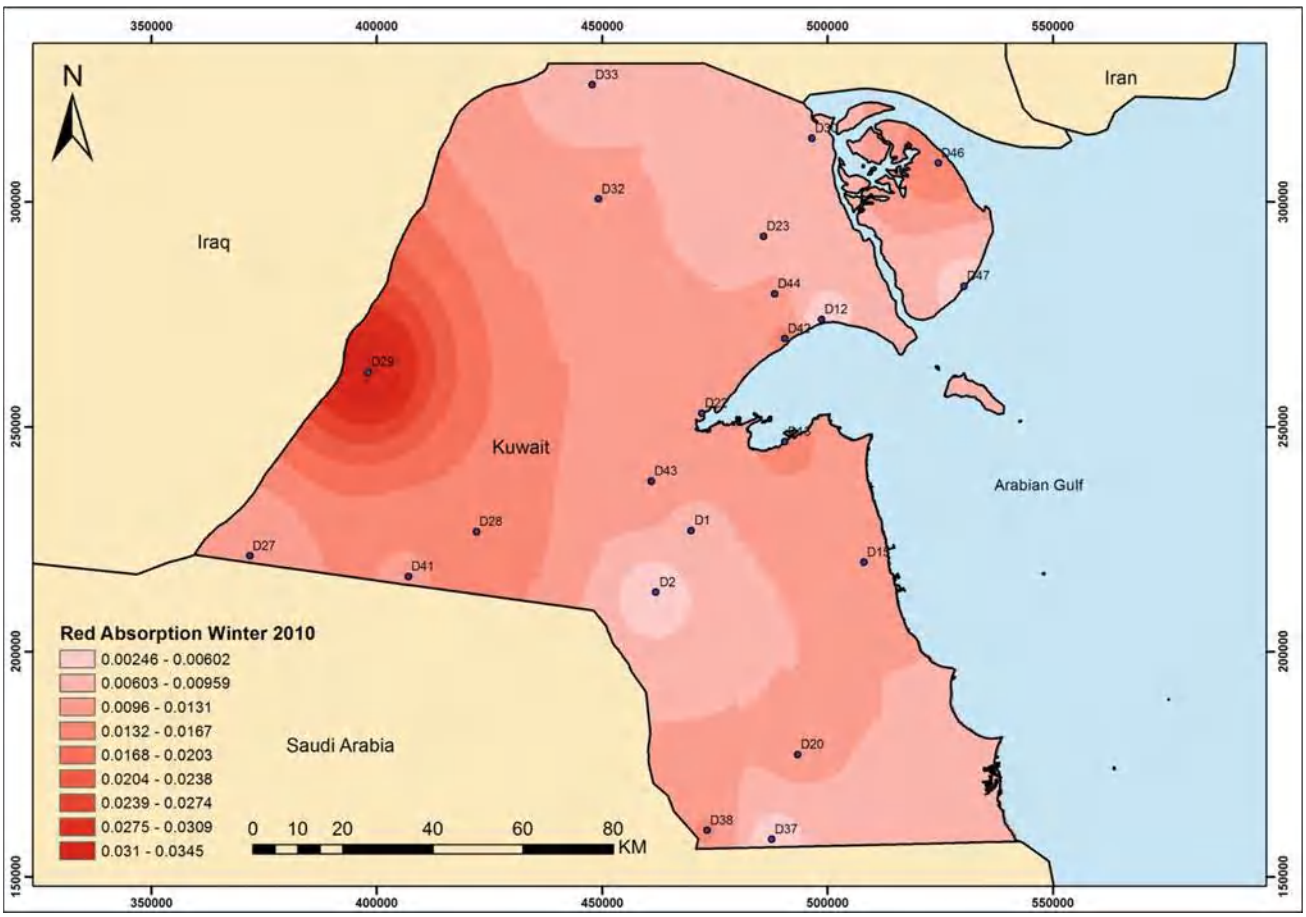

Fig. 9.26 Dust absorption of red light in winter 2010

IR Absorption Winter 2010

The red light absorbed by dust particles in winter varies throughout the State of Kuwait. The dust shows high absorption of red light across three main locations: the northeastern border with Saudi Arabia at Abraq (collector D29), Abdulia-Managish Road (collector D2), and at the border with Saudi Arabia at Um Jethathil (collector D41). The dust shows mid-high absorption of red light at various places in Kuwait, including Kathma (collector D22), north of Kuwait Bay at Bahra coastal zone (collector D12), and the western border with Saudi Arabia (collector D37). The dust shows medium absorption of red light at various other places, including the southern Kuwait-Saudi Arabia border zone (collector D38), on Bubiyan Island (collector D46), at the mid-western area of Kuwait (collectors 28), at Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), and at the KISR's main building location in Kuwait Bay (collector D13). However, the dust shows low absorption of red light at the northern area in Um Qasir/Bahaith (collector D30), on the northern border with Iraq at Ritqa (collector D33), and at Homa (collector D32). Finally, the dust shows very low absorption of red light across six main locations in Kuwait: on Bubiyan Island (collector 47), at gate Sabriya oil field (collector D23), at Kabd station (collector D1), in the KISR's petroleum center in Ahmadi (collector 15), and in the southern part of Kuwait (collector D20) (Fig. 9.27).

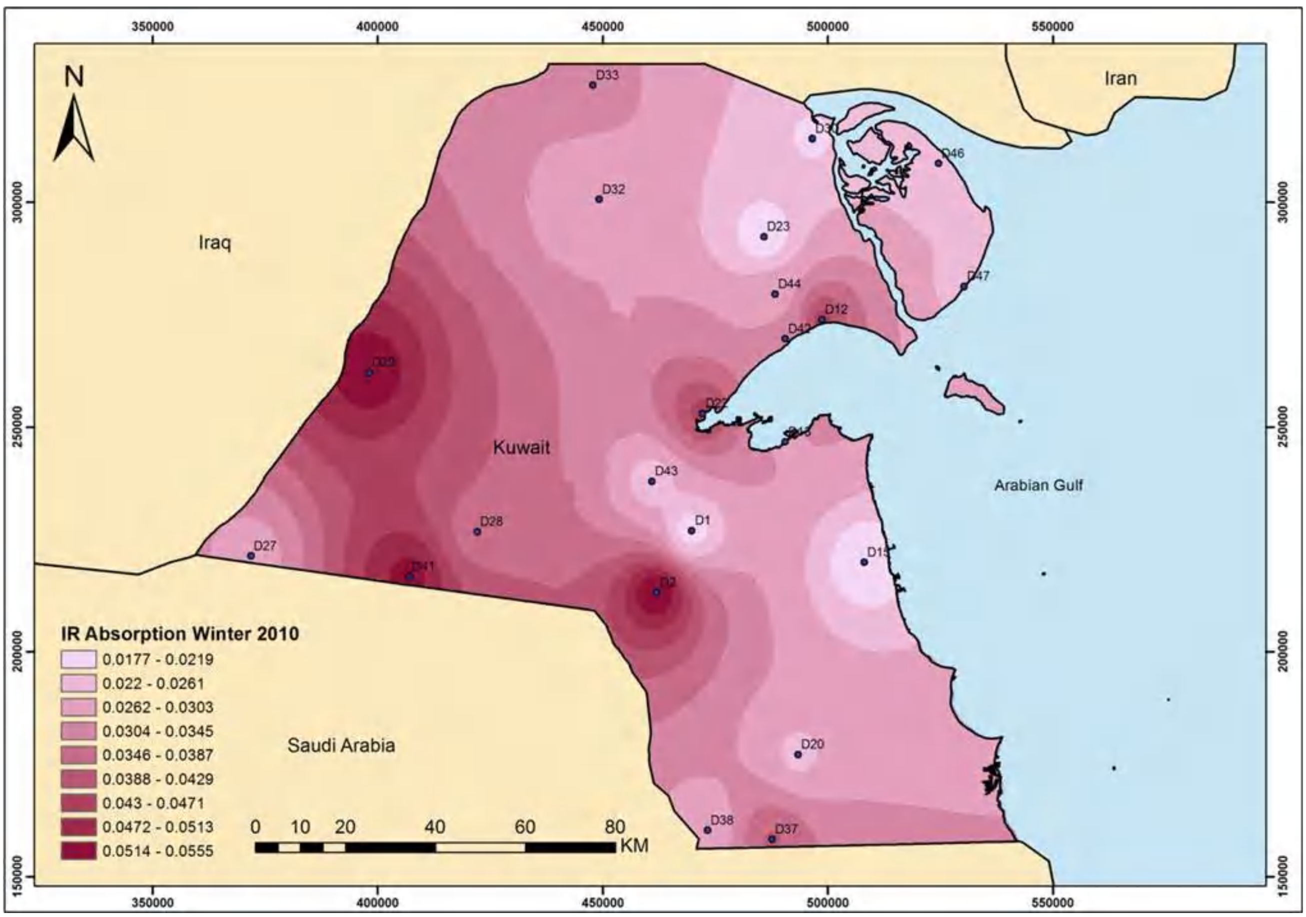

Fig. 9.27 Dust absorption of infrared light in winter 2010

UV Absorption Spring 2010

The absorbed ultraviolet light in spring varies throughout Kuwait. The absorption of ultraviolet light was high across four main locations in Kuwait that are represented by dark violet on the above map. These locations are in the north at Um Nega area (collector D31) and at North Um Qawati (collector D34), and along the northwestern border with Iraq (collector 35), as well as the southern border with Saudi Arabia (collector D39).

The dust shows mid-high absorption across various areas in Kuwait. These areas are North Ahmad Al-Jaber Air Base (collector D4), at Mutla (collector D5), at North Mutla (collector D6), at Raudhatain gate (D8), at North Sabiya (collector D11), at Ras Zur-Wafra (collector D18), et al. Wafra (collector D19), at Kathma (collector D22), at Salmi border zone (collector D27), at Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), at Bubiyan-Northeast (collector D46), at Ritqa (collector D33), at Huwaimiliyah (collector D35), and at the Kuwait-Saudi Arabia border zone (collector D39).

The dust shows medium absorption of ultraviolet at the western side of Burgan oil field (collector D3), at Liyah (collector D7), et al. Wafra (collector D19),at Wafra animal farm (collector D20), at Um Qawati (collector D24), at Poultry mid-way Salmi road (collector D38), and at the Kuwait-Saudi Arabia border zone (collector D40).

The dust shows low absorption of ultraviolet light in five locations in Kuwait. These locations are Abdulia-Managish Road (collector D2), the western side of Burgan oil field (collector D3), the Kuwait-Saudi Arabia border zone (collector D36), Um Jethathil (collector D41), and Sabah Al-Ahmad Nature Reserve (collector D43). Finally, the dust shows very low absorption of ultraviolet light across five various locations in Kuwait: the South Buffer zone at (collector D25), at Poultry mid-way Salmi road (collector D28), at the KISR's Salmiya station (Collector D14), at the KISR's main building Shuwaikh (Collector D13), and at Um Qasir/Bahaith (collector D30) (Fig. 9.28).

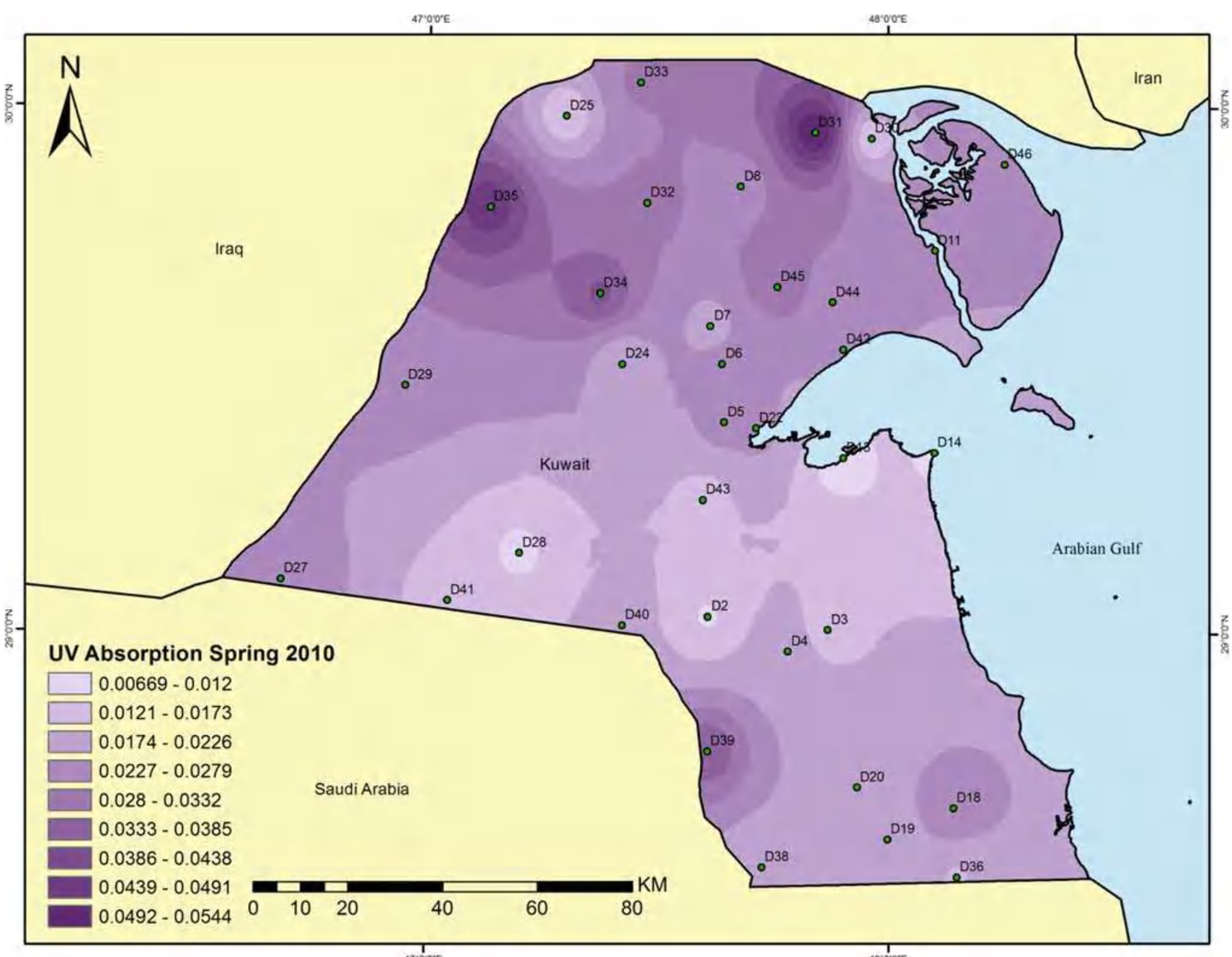

Fig. 9.28 Dust absorption of ultraviolet light in spring 2010

Violet Absorption Spring 2010

The violet light absorbed in spring varies throughout Kuwait. The absorption of violet light was high at four main locations in Kuwait represented by dark violet on the above map. These locations are in the north at Um Nega (collector D31) and at North Um Qawati (collector D34), and along the northwestern border with Iraq (collector 35), as well as the southern border with Saudi Arabia (collector D39).

The dust shows mid-high absorption across various areas in Kuwait. These areas are North Ahmad Al-Jaber Air Base (collector D4), Mutla (collector D5), North Mutla (collector D6), Raudhatain gate (D8), North Sabiya (collector D11), Ras Zur-Wafra (collector D18), Al Wafra (collector D19), Kathma (collector D22), Salmi border zone (collector D27), Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), Bubiyan-Northeast (collector D46), Ritqa (collector D33), Huwaimiliyah (collector D35), and the Kuwait-Saudi Arabia border zone (collector D39).

The dust shows medium absorption of violet at the western side of Burgan oil field (collector D3), at Liyah (collector D7), at Wafra animal farm (collector D20), at Poultry mid-way Salmi road (collector D38), and at the Kuwait-Saudi Arabia border zone (collector D40).

The dust shows low absorption of violet light across four locations in Kuwait: the western side of Burgan oil field (collector D3), Um Jethathil (collector D41), the KISR's Salmiya station (Collector D14), Um Qasir/Bahaith (collector D30), and Um Qawati (collector D24).

The dust shows very low absorption of violet lights across seven various locations in Kuwait, represented by very light violet on the map. These locations are the Abdulia-Managish Road (collector D2), the Sabah Al-Ahmad Nature Reserve (collector D43), the South Buffer zone (collector D25), the Poultry mid-way Salmi road (collector D28), the Kuwait-Saudi Arabia border zone (collector D36), Al Wafra (collector D19), and the KISR's main building Shuwaikh (Collector D13) (Fig. 9.29).

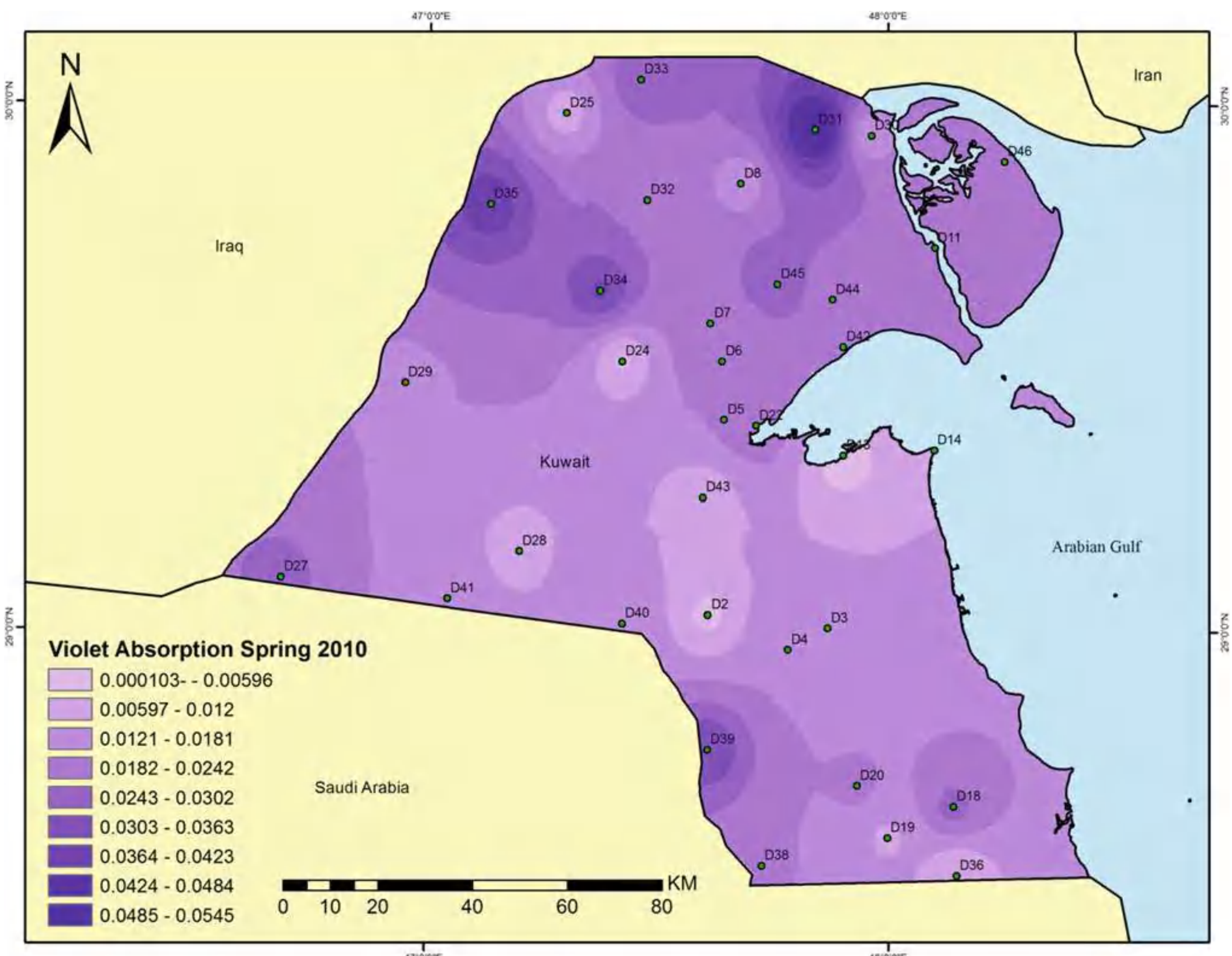

Fig. 9.29 Dust absorption of violet light in spring 2010

Blue Absorption Spring 2010

The absorbed blue light in spring varies throughout Kuwait. The absorption of blue light was high at four main locations in Kuwait represented by dark blue on the above map. These locations are in the north at Um Nega (collector D31) and at North Um Qawati (collector D34), and along the northwestern border with Iraq (collector 35), as well as the southern border with Saudi Arabia (collector D39).

The dust shows mid-high absorption various areas across Kuwait. These areas are North Ahmad Al-Jaber Air Base (collector D4), Mutla (collector D5), North Mutla (collector D6), Raudhatain gate (D8), North Sabiya (collector D11), Ras Zur-Wafra (collector D18), Al Wafra (collector D19), Kathma (collector D22), Salmi border zone (collector D27), Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), Bubiyan-Northeast (collector D46), Ritqa (collector D33), Huwaimiliyah (collector D35), and the Kuwait-Saudi Arabia border zone (collector D39).

The dust shows medium absorption of blue at the western side of Burgan oil field (collector D3), at Liyah (collector D7), at Wafra animal farm (collector D20), at Poultry mid-way Salmi road (collector D38), and at the Kuwait-Saudi Arabia border zone (collector D40).

The dust shows low absorption of blue light across five locations in Kuwait: the western side of Burgan oil field (collector D3), Um Jethathil (collector D41), the KISR's Salmiya station (Collector D14), Um Qasir/Bahaith (collector D30), and the northeastern border with Saudi Arabia at Abraq (collector D29).

kThe dust shows very low absorption of blue lights across eight locations in Kuwait, represented by very light blue on the map. These locations are the Abdulia-Managish Road (collector D2), Sabah Al-Ahmad Nature Reserve (collector D43), Um Qawati (collector D24), the South Buffer zone (collector D25), Poultry mid-way Salmi road (collector D28), the Kuwait-Saudi Arabia border zone (collector D36), Al Wafra (collector D19), and the KISR's main building Shuwaikh (Collector D13) (Fig. 9.30).

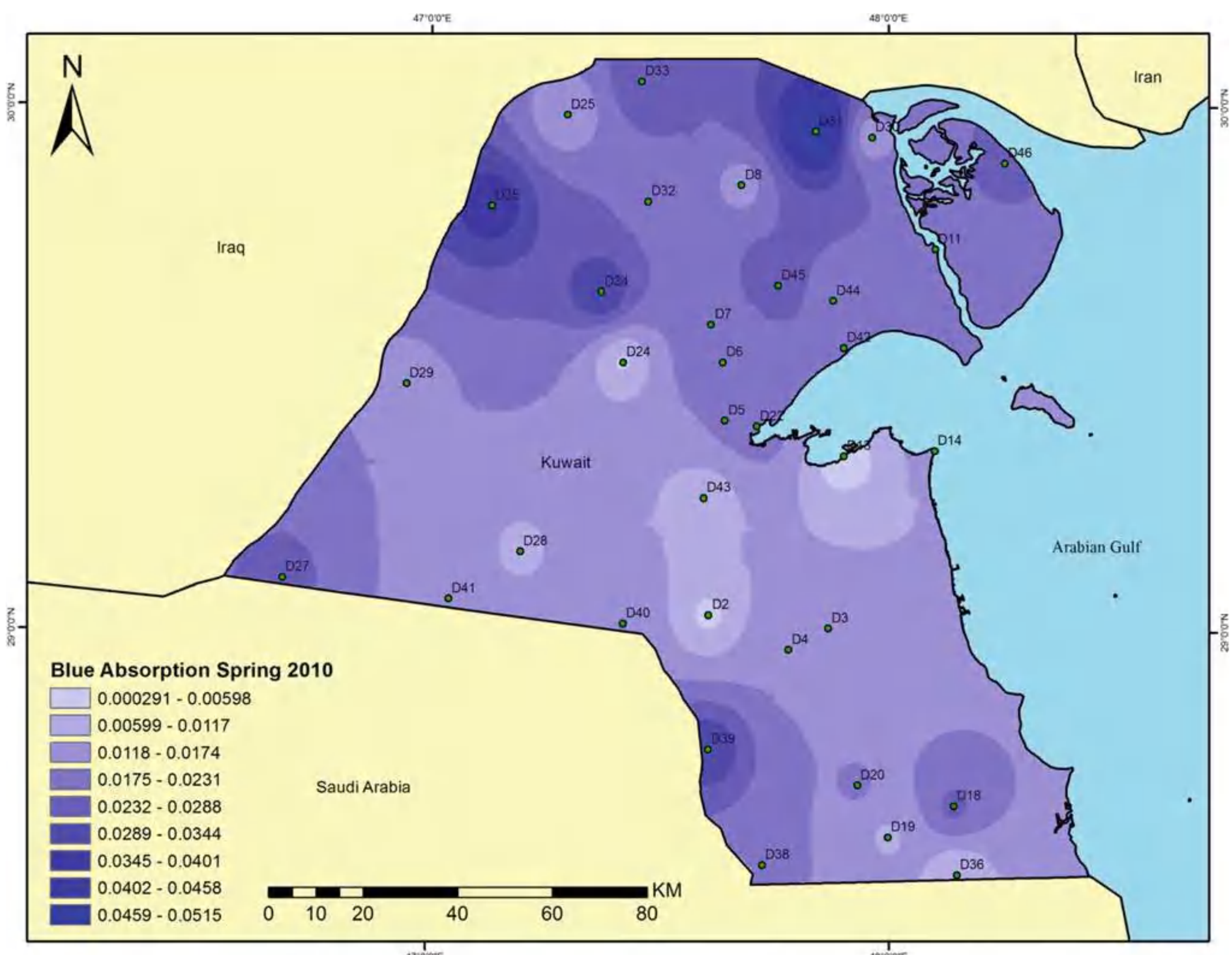

Fig. 9.30 Dust absorption of blue light in spring 2010

Cyan Absorption Spring 2010

The cyan light absorbed in spring varies throughout Kuwait. The absorption of cyan light is high at four main locations in Kuwait, represented by dark cyan on the above map. These locations are in the north at Um Nega (collector D31) and North Um Qawati (collector D34), and along the north-western border with Iraq (collector 35), as well as the southern border with Saudi Arabia (collector D39).

The dust shows mid-high absorption in various areas across Kuwait. These areas are North Ahmad Al-Jaber Air Base (collector D4), Mutla (collector D5), North Mutla (collector D6), Raudhatain gate (D8), North Sabiya (collector D11), Ras Zur-Wafra (collector D18), Al Wafra (collector D19), Kathma (collector D22), Salmi border zone (collector D27), Sabah Al-Ahmad Natural Reserve (collectors D42 and D44), Bubiyan-Northeast (collector D46), Ritqa (collector D33), Huwaimiliyah (collector D35), and the Kuwait-Saudi Arabia border zone (collector D39).

The dust shows medium absorption of cyan at the western side of Burgan oil field (collector D3), at Liyah (collector D7), at Wafra animal farm (collector D20), at Poultry mid-way Salmi road (collector D38), and at the Kuwait-Saudi Arabia border zone (collector D40).

The dust shows low absorption of cyan light across five locations in Kuwait: the western side of Burgan oil field (collector D3), Um Jethathil (collector D41), the KISR's Salmiya station (Collector D14), Um Qasir/Bahaith (collector D30), and the northeastern border with Saudi Arabia at Abraq (collector D29).

The dust shows very low absorption of cyan light across eight various locations in Kuwait, represented by the very light cyan on the map. These locations are the Abdulia-Managish Road (collector D2), Sabah Al-Ahmad Nature Reserve (collector D43), Um Qawati (collector D24), the South Buffer zone (collector D25), Poultry mid-way Salmi road (collector D28), the Kuwait-Saudi Arabia border zone (collector D36), Al Wafra (collector D19), and the KISR's main building Shuwaikh (collector D13) (Fig. 9.31).

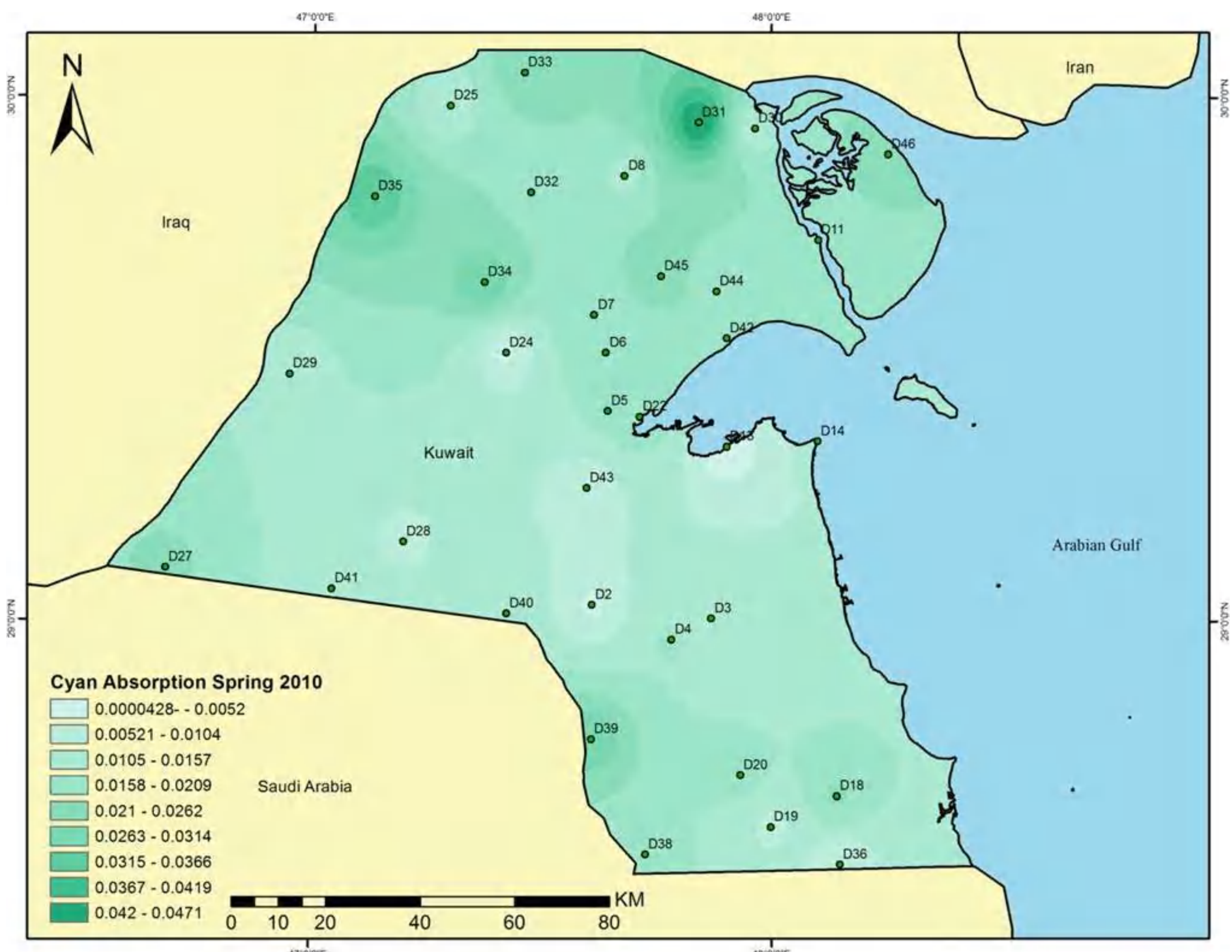

Fig. 9.31 Dust absorption of cyan light in spring 2010

Green Absorption Spring 2010

The green light absorbed in spring varies throughout Kuwait. The absorption of green light is high across four main locations in Kuwait, represented by dark green on the above map. These locations are in the north at Um Nega (collector D31) and North Um Qawati (collector D34), and along the northwestern border with Iraq (collector 35), as well as the southern border with Saudi Arabia (collector D39).

The dust shows mid-high absorption across various areas in Kuwait. These areas are North Ahmad Al-Jaber Air Base (collector D4), Mutla (collector D5), North Mutla (collector D6), Raudhatain gate (D8), North Sabiya (collector D11), Ras Zur-Wafra (collector D18), Al Wafra (collector D19), Kathma (collector D22), Salmi border zone (collector D27), Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), Bubiyan-Northeast (collector D46), Ritqa (collector D33), Huwaimiliyah (collector D35), and the Kuwait-Saudi Arabia border zone (collector D39).

The dust shows medium absorption of green at the western side of Burgan oil field (collector D3), at Liyah (collector D7), at Wafra animal farm (collector D20), at Poultry mid-way Salmi road (collector D38), and at the Kuwait-Saudi Arabia border zone (collector D40).

The dust shows low absorption of green light in five locations in Kuwait: the western side of Burgan oil field (collector D3), Um Jethathil (collector D41), the KISR's Salmiya station (Collector D14), Um Qasir/Bahaith (collector D30), and the northeastern border with Saudi Arabia at Abraq (collector D29).

The dust shows very low absorption of green lights across eight locations in Kuwait, represented by very light green on the map. These locations are Abdulia-Managish Road (collector D2), Sabah Al-Ahmad Nature Reserve (collector D43), Um Qawati (collector D24), the South Buffer zone (collector D25), Poultry mid-way Salmi road (collector D28), the Kuwait-Saudi Arabia border zone (collector D36), Al Wafra (collector D19), and the KISR's main building Shuwaikh (collector D13) (Fig. 9.32).

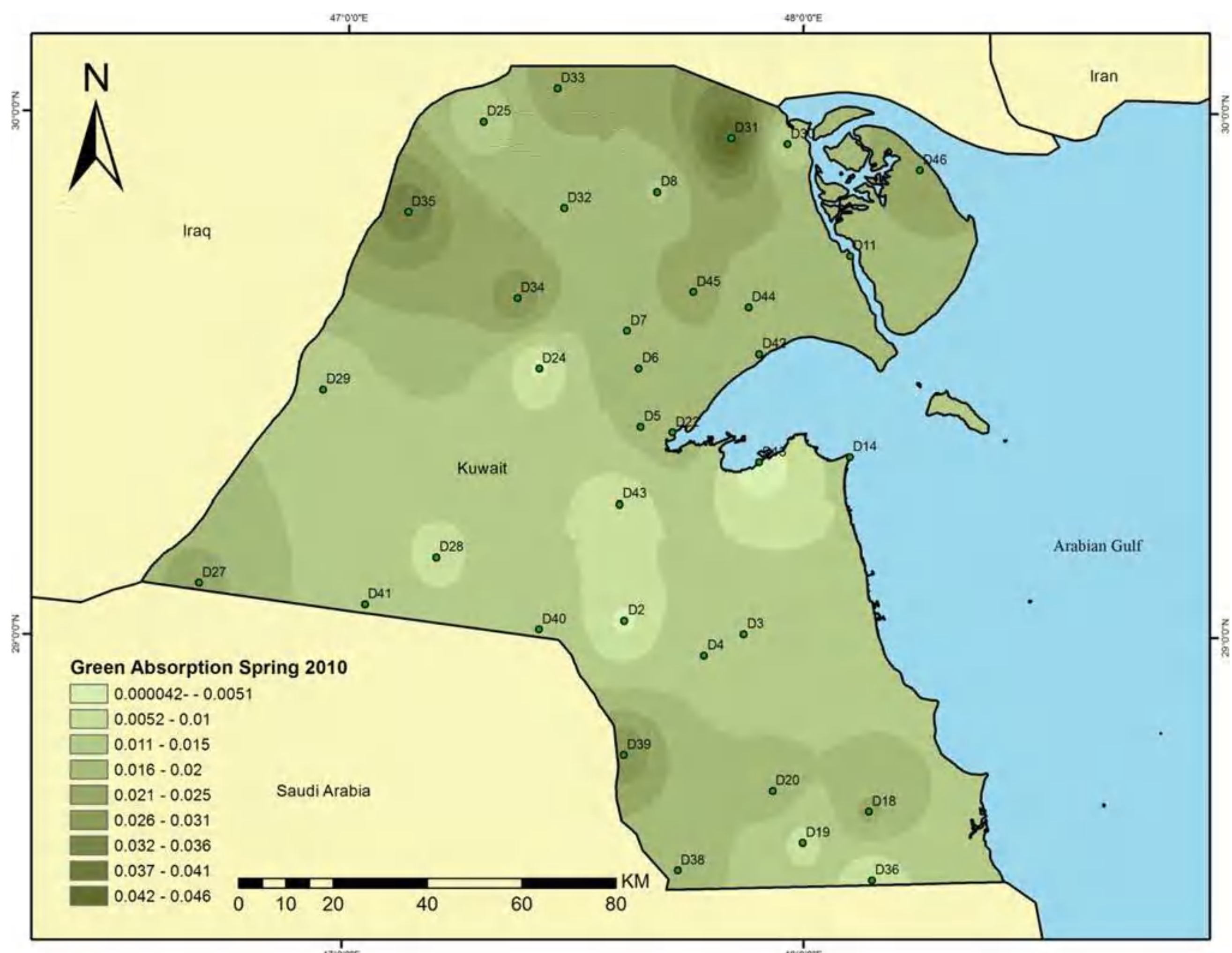

Fig. 9.32 Dust absorption of green light in spring 2010

Yellow Absorption Spring 2010

The yellow light absorbed in spring varies throughout Kuwait. The absorption of yellow light was high at four main locations in Kuwait, represented by dark yellow on the above map. These locations are in the north at Um Nega (collector D31) and North Um Qawati (collector D34), and along the northwestern border with Iraq (collector 35), as well as the southern border with Saudi Arabia (collector D39).

The dust shows mid-high absorption in various areas across the State of Kuwait. These areas are North Ahmad Al-Jaber Air Base (collector D4), Mutla (collector D5), North Mutla (collector D6), Raudhatain gate (D8), North Sabiya (collector D11), Ras Zur-Wafra (collector D18), Al Wafra (collector D19), Kathma (collector D22), Salmi border zone (collector D27), Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), Bubiyan-Northeast (collector D46), Ritqa (collector D33), Huwaimiliyah (collector D35), and the Kuwait-Saudi Arabia border zone (collector D39).

The dust shows medium absorption of yellow at the western side of Burgan oil field (collector D3), at Liyah (collector D7), at Wafra animal farm (collector D20), at Poultry mid-way Salmi road (collector D38), and at the Kuwait-Saudi Arabia border zone (collector D40).

The dust shows low absorption of yellow light across five locations in Kuwait: the western side of Burgan oil field (collector D3), Um Jethathil (collector D41), the KISR's Salmiya station (collector D14), Um Qasir/Bahaith (collector D30), and the northeastern border with Saudi Arabia at Abraq (collector D29).

The dust shows very low absorption of yellow light across eight locations in Kuwait, represented by the very light yellow on the map. These locations are Abdulia-Managish Road (collector D2), Sabah Al-Ahmad Nature Reserve (collector D43), Um Qawati (collector D24), the South Buffer zone (collector D25), Poultry mid-way Salmi road (collector D28), the Kuwait-Saudi Arabia border zone (collector D36), Al Wafra (collector D19), and the KISR's main building Shuwaikh (collector D13) (Fig. 9.33).

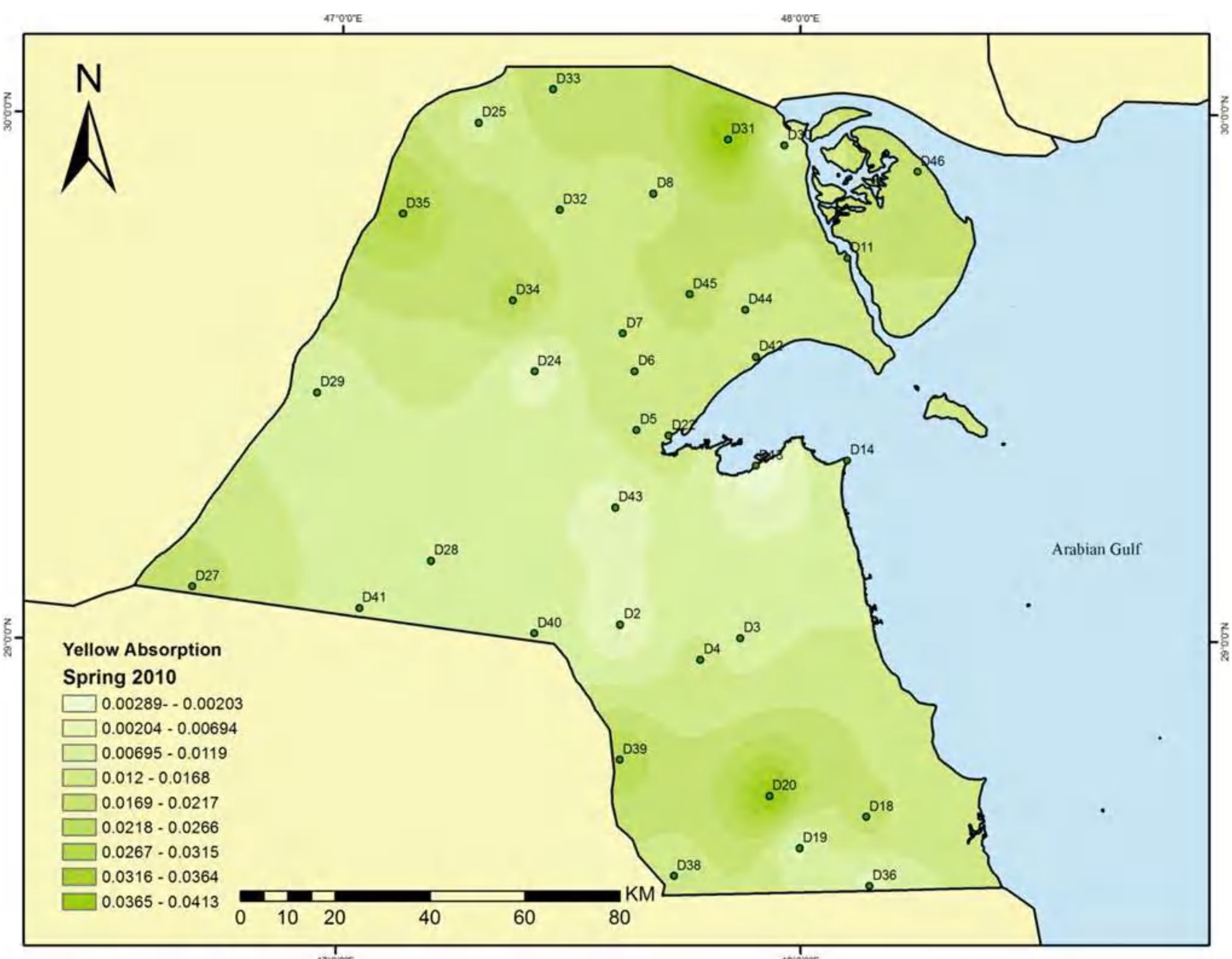

Fig. 9.33 Dust absorption of yellow light in spring 2010

Orange Absorption Spring 2010

The orange light absorbed in spring varies throughout Kuwait. The absorption of orange light was high across four main locations in Kuwait, represented by dark orange on the above map. These locations are the in north at Um Nega (collector D31) and North Um Qawati (collector D34), and along the northwestern border with Iraq (collector 35), as well as the southern border with Saudi Arabia (collector D39).

The dust shows mid-high absorption across various areas in Kuwait. These areas are North Ahmad Al-Jaber Air Base (collector D4), Mutla (collector D5), North Mutla (collector D6), Raudhatain gate (D8), North Sabiya (collector D11), Ras Zur-Wafra (collector D18), et al. Wafra (collector D19), at Kathma (collector D22), at Salmi border zone (collector D27), at Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), at Bubiyan-Northeast (collector D46), at Ritqa (collector D33), at Huwaimiliyah (collector D35), and at the Kuwait-Saudi Arabia border zone (collector D39).

The dust shows medium absorption of orange at the western side of Burgan oil field (collector D3), at Liyah (collector D7), at Wafra animal farm (collector D20), at Poultry mid-way Salmi road (collector D38), and at the Kuwait-Saudi Arabia border zone (collector D40).

The dust shows low absorption of orange light in five locations in Kuwait: the western side of Burgan oil field (collector D3), Um Jethathil (collector D41), the KISR's Salmiya station (collector D14), Um Qasir/Bahaith at (collector D30), and the northeastern border with Saudi Arabia at Abraq (collector D29).

The dust shows very low absorption of orange light across eight locations in Kuwait, represented by the very light orange on the map. These locations are Abdulia-Managish Road (collector D2), Sabah Al-Ahmad Nature Reserve (collector D43), Um Qawati (collector D24), the South Buffer zone (collector D25), Poultry mid-way Salmi road (collector D28), the Kuwait-Saudi Arabia border zone (collector D36), Al Wafra (collector D19), and the KISR's main building Shuwaikh (collector D13) (Fig. 9.34).

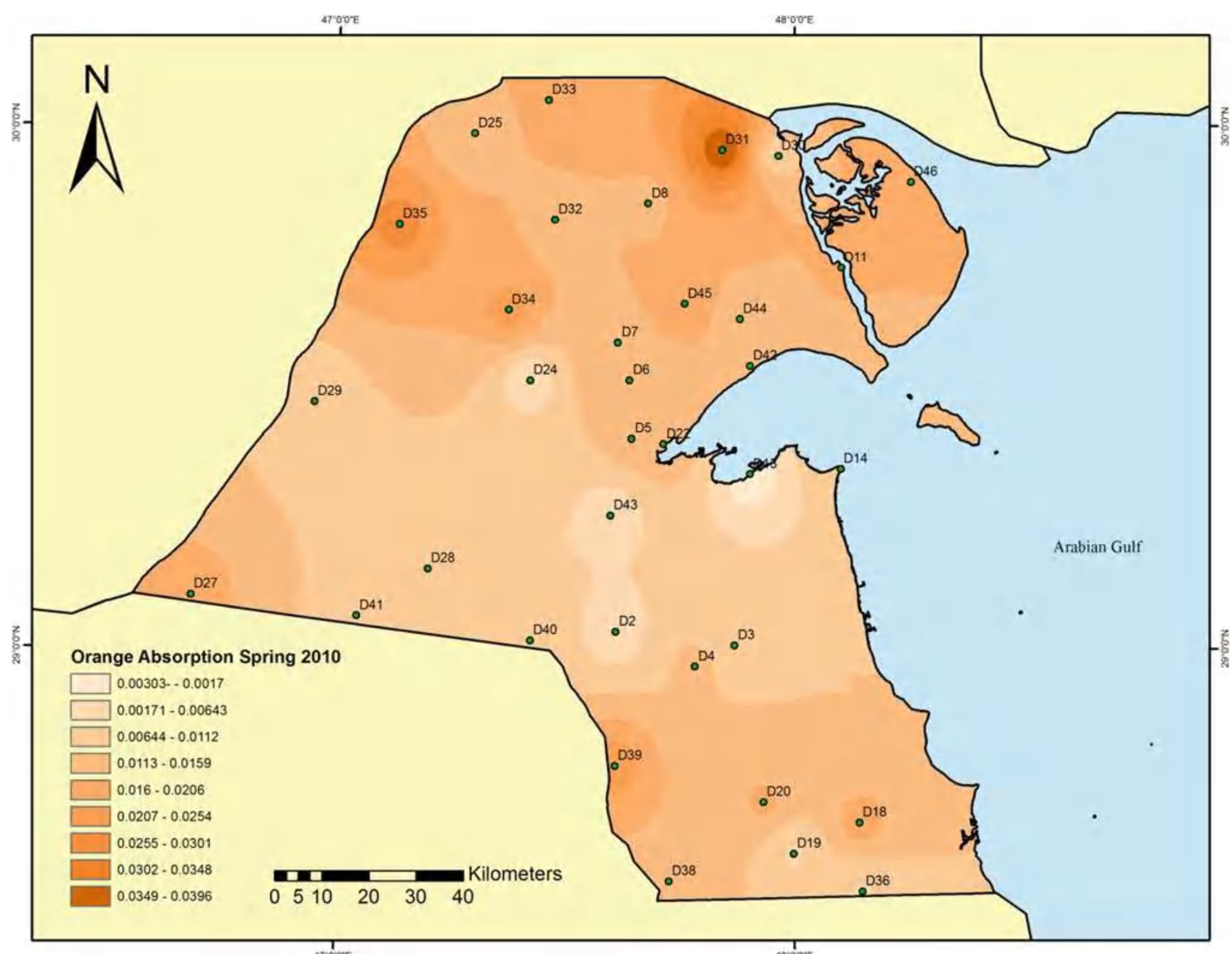

Fig. 9.34 Dust absorption of orange light in spring 2010

Red Absorption Spring 2010

The red light absorbed in spring varies throughout Kuwait. The absorption of red light was high at four main locations in Kuwait, represented by dark red on the above map. These locations are in the north at Um Nega (collector D31) and North Um Qawati (collector D34), and along the north-western border with Iraq (collector 35), as well as the southern border with Saudi Arabia (collector D39).

The dust shows mid-high absorption in various areas across the State of Kuwait. These areas are North Ahmad Al-Jaber Air Base (collector D4), Mutla (collector D5), North Mutla (collector D6), Raudhatain gate (D8), North Sabiya (collector D11), Ras Zur-Wafra (collector D18), Al Wafra (collector D19), Kathma (collector D22), Salmi border zone (collector D27), Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), Bubiyan-Northeast (collector D46), Ritqa (collector D33), Huwaimiliyah (collector D35), and the Kuwait-Saudi Arabia border zone (collector D39).

The dust shows medium absorption of red at Liyah (collector D7), at Wafra animal farm (collector D20), at the southern border with Saudi Arabia (collector D38), and at the Kuwait-Saudi Arabia border zone (collectors D40 and 41).

The dust shows low absorption of red light in five locations in Kuwait: the western side of Burgan oil field (collector D3), Um Jethathil (collector D41), the KISR's Salmiya station (Collector D14), the northeastern border with Saudi Arabia at Abraq (collector D29), the Kuwait-Saudi Arabia border zone (collector D36), Al Wafra (collector D19), Poultry mid-way Salmi road (collector D28), and the South Buffer zone (collector D25).

The dust shows very low absorption of red light across five locations in Kuwait, represented by the very light red on the map. These locations are Abdulia-Managish Road (collector D2), Sabah Al-Ahmad Nature Reserve (collector D43), Um Qawati (collector D24), Um Qasir/Bahaith (collector D30), and the KISR's main building Shuwaikh (collector D13) (Fig. 9.35).

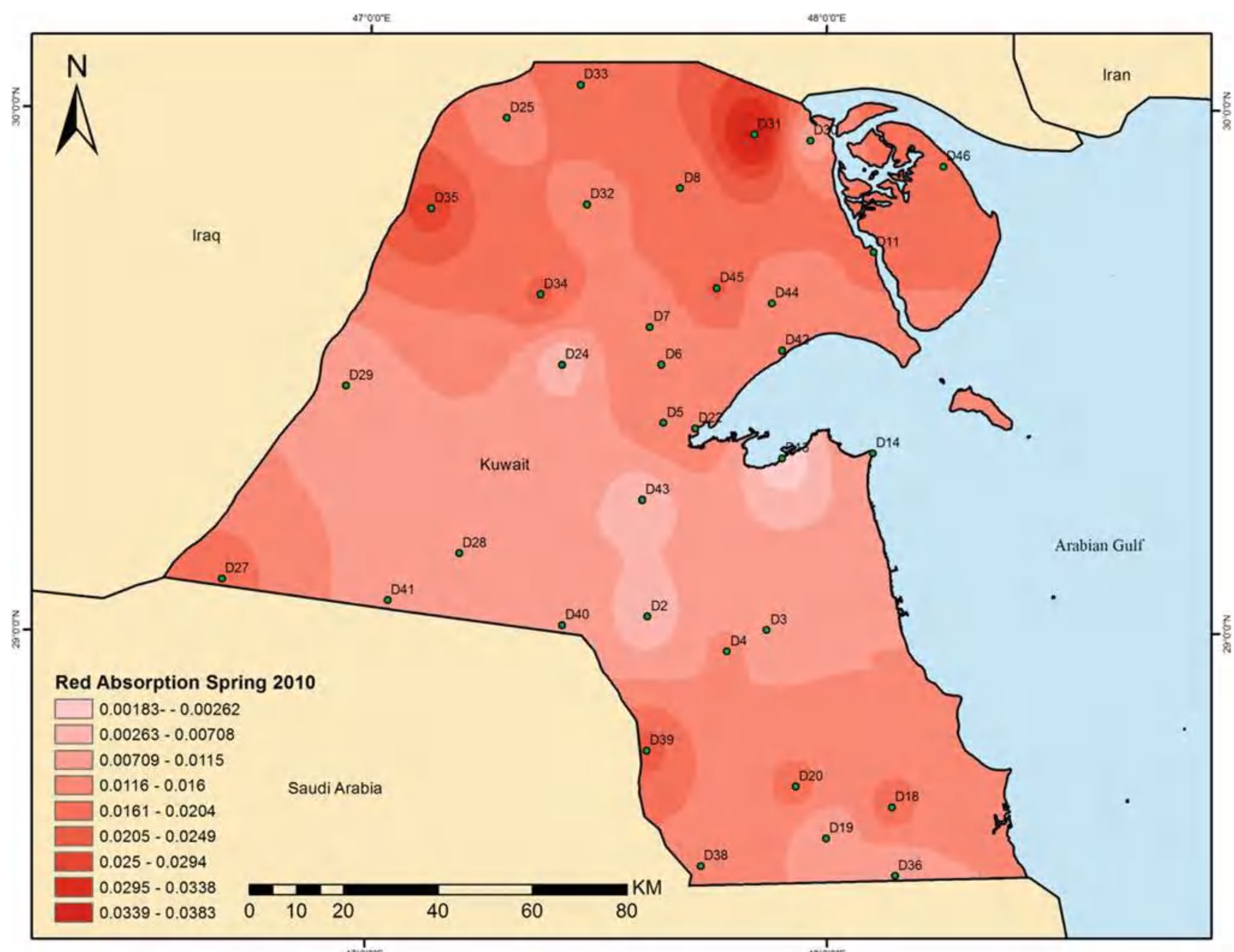

Fig. 9.35 Dust absorption of red light in spring 2010

Infrared Absorption Spring 2010

The absorbed red light in spring varies throughout Kuwait. The dust shows high absorption at five main locations across Kuwait, represented by the dark red on the above map. These locations are at Um Nega (collector D31), at the South Buffer zone (collector D25), at Raudhatain gate (D8), at Um Jethathil (collector D41), and at Salmi border zone (collector D27).

The dust absorbs mid-high infrared light at several locations: Sabah Al-Ahmad Nature Reserve (collector D43), Poultry mid-way Salmi road (collector D38), Ras Zur-Wafra (collector D18), the western side of Burgan oil field (collector D3), Ritqa (collector D33), North Um Qawati (collector D34), Huwaimiliyah (collector D35), the Kuwait-Saudi Arabia border zone (collector D39), North Ahmad Al-Jaber Air Base (collector D4), Mutla (collector D5), North Mutla (collector D6), North Sabiya (collector D11), Al Wafra (collector D19), Kathma (collector D22), Salmi border zone (collector D27), Sabah Al-Ahmad Nature Reserve (collectors D42 and D44), and Bubiyan-Northeast (collector D46).

The dust shows medium absorption at the western side of Burgan oil field (collector D3), at Liyah (collector D7), et al. Wafra (collector D19),at Wafra animal farm (collector D20), at Um Qawati (collector D24), at Um Qasir/Bahaith (collector D30), and at the Kuwait-Saudi Arabia border zone (collector D40).

The dust shows a very low absorption at four main locations, represented by the light red on the map in Fig. 9.36. These locations are Abdulia- Managish Road (collector D2), Poultry mid-way Salmi road (collector D28), the Kuwait-Saudi Arabia border zone (collector D36), and the KISR's main building location in Kuwait Bay (collector D13).

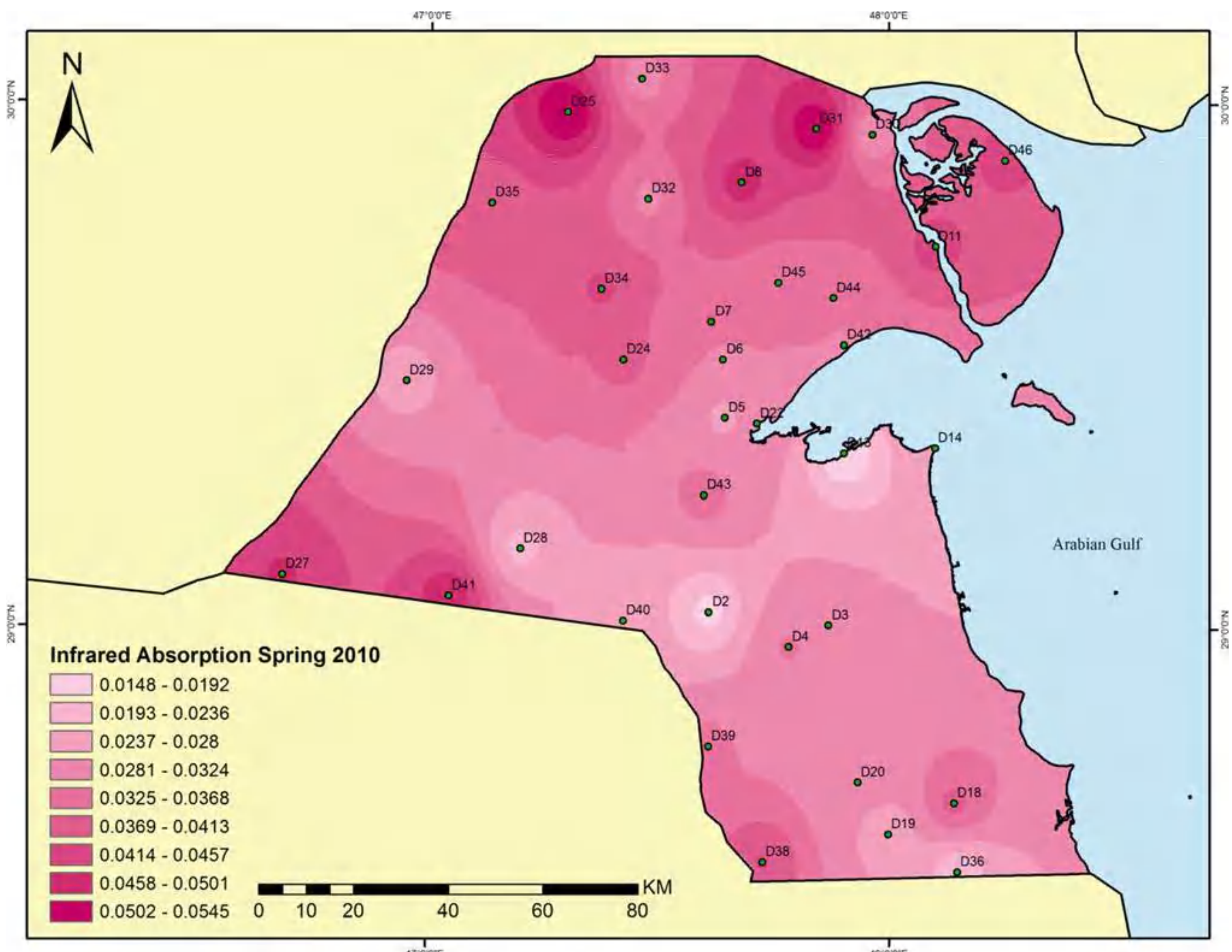

Fig. 9.36 Dust absorption of infrared light in spring 2010

From the UV–VIS maps of absorption in different seasons across Kuwait, it is clear that the dust absorption for the UV–VIS light radiation varies from month to month and season to season. The Fourier transformer infrared data clarify these phenomena in the following section.

Furrier Transformer Infrared (FT-IR (MID)

The collectors showed that the chemical functional group, chemical bounding, and chemical elements vary for the same collectors in different seasons. The dust for the same collector contained the same functional groups; however, it contained different structures, such as the silicon group. In December, the D3 collector had Si_2O only; whereas, in September, the same collector had more silicon functional groups, such as Si–OH, Si–F, and Si_2O. Some chemicals appeared during some seasons and disappeared during others, such as the nitrite functional group R–O–N=O, which was found in the December collector; however, it disappeared from the March and September collectors.

From the study of the collectors for the four seasons, the dust chemicals in the collectors changed depending on the weather conditions and the nature of the area. Dust content that has a nitrogen compound, such as the amide, the amine, or the nitro, appeared in a few collectors. The dust mostly contained silicon (Si) compounds, hydrocarbons (CH), sulfur (sulphur) (S), phosphorus (P), and halogens (F, Cl, Br, I). The three tables for the D-3 collector (Tables 9.1, 9.2, and 9.3) show how the chemical compound varies from season to season. Seasonal Color Spectrophotometric Variations of Dust Samples within Kuwait, April 2014.

Table 9.1 Collector D-3 December 2010

No	Function Group	Compound	Bounds	Peak Regions (cm^{-1})	
				From	**To**
1	Alkanes	R–CH_2–R”	CH CH CH	2936 2863 1485	2916 2843 1445
		R$(CH_2)_4$–C	CH CH CH CC	2936 2863 1485 750	2916 2843 1445 720
		RCH_3	CH CH CH CH	2972 2882 1475 1380	2952 2862 1435 1385
2	Ketones	RCO–Ph#NH_2	C=O	1655	1635
		4C ring K	C=O	1785	1765
		Fused ring	C=O	1655	1635
3	Nitrite	R–O–N =O	N=O N=O N–O	1681 1625 814	1648 1605 751
4	Phosphorus	P=S	P=S	800	580
5	Silicon	Si–OH	O–H Si–OH Si–O	3700 1040 910	3200 1020 830
		Si–O–Si	Si–O–Si	1020	1010
		Si–O–C Si–O–C	Si–O–C Si–O–C	1100 990	1000 945
		Si–Cl	Si–Cl	550	470
7	Sulfur	S=S	S=S	500	400
		R–SO_3 H_3O	H_3O SO_3	2800 1230	1650 1120

Table 9.2 Sample D-3 28-3-2010

No	Function group	Compound	Bounds	Peak regions (cm^{-1})	
				From	**To**
1	Ethers	4-Ring ETH	C–O–C C–O–C	1035 990	1020 975
		6-Ring ETH	C–O–C C–O–C	1110 820	1090 805
2	Halogens	C–Br	C–Br	600	500
		C–I	C–I	610	485
3	Ketones	Ph–CO–Ph	C=O	1670	1660
		RCO–Ph#NH_2	C=O	1655	1635
		C=C–CO–C=C	C=O	1670	1663
		Quinones	C=O	1655	1635
4	Phosphorus	P=S	P=S	800	580
5	SILICONS	Si–O–Si	Si–O–Si	1020	1010
6	Sulfur	C=S	C=S	1200	1050
		S–S	S–S	500	400
		R–SOOH	O–H S=O S–O	2790 1090 870	2340 990 810

Table 9.3 Sample D-3 28-9-2010

No	Function group	Compound	Bounds	Peak regions (cm^{-1})	
				From	**To**
1	Alkanes	Ph–CH_3	CH CH	2930 2870	2920 2860
		R′–CH_2–R″	CH CH CH	2936 2863 1485	2916 2843 1445
2	Ethers	4-Ring ETH	C–O–C C–O–C	1035 990	1020 975
		6-Ring ETH	C–O–C C–O–C	1110 820	1090 805
3	Halogens	C–Br	C–Br	600	500
		C–I	C–I	610	485
4	Ketones	Ph–CO–Ph	C=O	1670	1660
		RCO–Ph#NH_2	C=O	1655	1635
		C=C–CO–C=C	C=O	1670	1663
		Quinones	C=O	1655	1635
5	SILICONS	Si–O–Si	Si–O–Si	1100	1000
		Si–F	Si–F	920	820
		Si–OH	O–H Si–OH Si–O	3700 1040 910	3200 1020 830
6	Sulfur	C=S	C=S	1200	1050
		S–S	S–S	500	400
		R–SOOH	O–H S=O S–O	2790 1090 870	2340 990 810

Conclusion

From the UV–VIS study and FT-IR study, it is clear that the absorbance of UV–VIS light varies from season to season and from month to month. The difference in absorbance is related to the change in the chemical content of dust. The FT-IR data are very important for revealing the different chemical content of dust and for quickly scanning what possible compounds can be found in dust particles when further analysis is required.

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Summary

The satellite images show seven major source areas of dust storm trajectories in the world:

(I) The Western and Southern Sahara Desert (Western Libya toward Morocco or south toward Nigeria and Ghana).
(II) The Eastern Sahara Desert (Eastern Libya toward Egypt and Palestine).
(III) Ethiopia-Southern Arabia (East Sudan and Ethiopia toward Southern Arabia).
(IV) Northern Arabia (Jordan toward Mesopotamia, Kuwait, and Bahrain).
(V) The Gobi Desert (Gobi Desert toward North China, Korea, and Japan).
(VI) The Taklimakan Desert (Taklimakan Desert toward east China or south to Afghanistan, Pakistan, and Baluchistan).
(VII) The Australian Desert (Northern Australia toward the West and Southern Australia toward the East).

This present study indicates that each zone of global dust storm trajectories has unique dust fallout characteristics regarding depositional rates, grain size, mineralogy, particle surface area, and variations between upwind and downwind. Dust fallout rates tend to diminish downwind, except in Zone IV, where the midpoint of the dust storm trajectory shows a higher amount of dust than the borders.

On average, mud particles represent 74% of dust samples, while the rest is formed by sand particles (26%). The average samples of the world's fallen dust are negatively skewed, trimodal, with a dominance of silt size fractions (61%). The grain-size trimodality might indicate multiple sources. All of the world's dust storm trajectories are fining downwind due to rapid deposition of sand size fractions. Zone IV is an exceptional case, in which the main trajectory passes from the Western Desert of Iraq through the Mesopotamian Floodplain, loading the wind with mud size fractions (97%), toward Kuwait (desert area), where fallen dust contains 37% sand particles (UNEP 2016; Al-Dousari et al. 2017; Al-Dousari and Al-Hazza 2013; Al-Ghadban et al. 2008).

The mineralogical and surface area comparison between collected dust in this study and mud particles from surface sediments surrounding the traps shows large variations, which indicate that the mud size particles predominantly originated from regional and global sources (Figs. 3 and 4). Other researchers support the long-distance origination of mud particles. Most of the exposed bedrock in Hawaii (USA) is basalt with little or no quartz, but the overlaying soil contains considerable quartz, which is believed to be blown as dust particles from North America across the Pacific Ocean (Péwé et al. 1981). Long-distance traveling dust is commonly composed of very fine particles, with the predominant sizes between 0.068 and 0.02 mm (Walker and Costing 1971).

Regarding the dust in Kuwait, the northwestern, western, and northern winds play major roles in the origin of dust storms to the study area. Regional areas represent the dominant sources of dust fallout, while local sources contribute appreciable amounts. The very fine and fine sand particles originate from local sources as they move in the form of saltation or short-term suspension for a short distance, representing 37% of the average dust fallout percentages in Kuwait. There is a trend of fining in Mean size for dust particles toward the east and the northeast. Carbonates and quartz are the major components of dust in Kuwait, and feldspars are found in appreciable amounts. Other minerals in the dust are gypsum, anhydrite, bassanite, and heavy minerals. The muddy playas, depressions, sabkhas, and intertidal zone (Bubiyan and Warba islands) are the major sources of local dust. Natural vegetation plays a major role in minimizing and reducing fallen dust. Open desert areas show an increase in the quantities of dust fallout by at least two-thirds more than in the National Park in Kuwait. Further studies should concentrate on other aerosols associated with dust (pollen, organic matter, hydrocarbons) rather than dust-control measures.

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The continuous monitored pollen and deposited dust in the State of Kuwait from August 2009 to August 2011 lead us to conclude that local and close regional flora are the main source of the pollen load. Except for very low percentages (2–3%) of *Pinaceae* pollen recorded in the north and north-west borders of Kuwait with Iraq (D9, 25, 27, 29, and 30), the remainder could be interpreted as being transported by the northwesterly wind from long-distance regional sources. The closest pine trees in the regional scale are in northern Iraq and Syria, Lebanon, and Turkey. It can also be concluded that areas that experience low depositional dust have a higher concentration of pollen. The years 2009–2010 experienced a high concentration of pollen but lower in the deposited dust compared with 2010–2011. This finding indicates the decrease in native vegetation in the regional and local areas, which caused the increase in deposited dust rates. The pollen counts can be taken as a good indicator of vegetation density deterioration rate. The pollen distribution reached its maximum peak at the end and the beginning of the of rainy season in spring (April–May) and fall (October–November), which indicates that the pollen concentration is highly related to climatic conditions and the distribution of drainage system (wadis). Spring marked the highest pollen distribution because of the flowering of a great number of *Chenopodiaceae, Gramineae (Poaceae), Cyperaceae, Leguminosae, and Plantaginaceae*. Summer (July–August) and winter (January–February) recorded a graph with a lower distribution of pollen due to the severe drought, dust storms, winter wind, and rainfall. Winter had the lowest pollen count. *Chenopodiaceae* are the most common trigger of allergies in Kuwait, but no correlations so far were noted between pollen and the number of asthma patients in Kuwait (Al-Dousari et al. 2016, 2018b).

Tamarix aphyllae, Prosopis juliflora and *Moringa pterigosperma* were found to be effective in controlling the eolian processes. The average sand accumulation around each tree within green belts is equivalent to 10 m^3, while it is equivalent to 1.92 m^3 for the dominant native plants in Kuwait. Although the trees are much larger in size, some native plants display better capability in controlling eolian sediments. The maximum volumes of sand accumulation were observed around *Nitraria retusa* (21.9 m^3), *Lycium shawii* (15.5 m^3), and *Haloxylon salicornium* (14.5 m^3), which is significant to consider them the most efficient native plants in controlling eolian sediments. Correspondingly, each native plant has its distinctive morphological properties (Ahmed et al. 2016; Ahmed and Al-Dousari 2013; Al-Awadhi and Al-Dousari 2013; Al-Dousari et al. 2018b, c). The green belts and native plants were found to be effective solutions in controlling eolian accumulations, and they have the potential to reduce costs. Therefore, green belts and native plants are recommended as potential future applications to control the sand encroachment problem and resuspended dust particles.

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