CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The thesis focused on shedding light on the dust loading, PM concentrations, physical and optical properties as well as chemical composition of dust for the first time over the Sistan region of southeastern Iran. The Sistan region is a closed topographic low basin surrounded by arid and rocky mountains and constitutes a major dust source region in south west Asia, while its northern part drains the Hilmand river, thus constituting a wetland area known as Hamoun Basin. Hamoun lakes complex have an area of about 4500 Km^2 with a water volumes of 13025 million m^3 and play the role of a "water cooler" for the region when they are full of water as the severe winds blow across the lakes. The Sistan depression at the end of basin is covered by Quaternary sediments with a maximum thickness of about 500 m in the central part of the plain that have been eroded by fluvial processes. The major portion of this sediment is made up of clay and silt. Therefore, fine-grained soils including silt and clay are the main surface cover the Sistan depression. Sistan has a population of about 400,000, of which half work in agricultural and animal domesticated fields. The economy is strongly dependent on agriculture and the goods and services provided by the wetlands.

Severe droughts over the past decades, especially after 1999, have caused desiccation of the Hamoun lakes, leaving a fine layer of sediment that is easily lifted by the wind and, therefore, making the basin one of the most active sources of dust in southwest Asia. The strong "Levar", especially during the summer season, blows fine sands off the exposed lake bed and deposits this detritus within huge dune bed forms that may cover a hundred or more villages along the former lakeshore. The drainage of the Hamoun wetlands, in association with the intense Levar winds in summer, is the main factor responsible for the frequent and massive dust storms over the Sistan region. Analysis of water surface in

combination with dust storms showed that the Hamoun dried beds have a strong effect on dust storms as sources of aerosols.

Systematic PM concentrations were measured in Zabol city, affected by the Sistan dust storms, covering the period September 2010 to August 2011. The results show that the PM_{10} concentrations were considerably higher than the corresponding European Union air quality annual standard. The air quality is affected by dust storms from the Sistan desert, which are very intense during summer. Hamoun dried beds cause a dramatic increase in PM_{10} concentrations and a deterioration of air quality (65% of the days were considered unhealthy for sensitive people and 34.9% as hazardous).

Dust loading from the Hamoun basin was found to have a significant contributing influence on the development of extreme dust storms, especially during the summer days. This influence, firstly was found to depend on the intensity and duration of dust storms, and secondly, on the distance from the source region, the wind speed and altitude. The grain-size distribution of the dust loading was strongly influenced by the distance from the dust source. Furthermore, the particle size distribution exhibited a shift towards lower values as the altitude increases, with this feature to be more obvious amongst larger size particles, while the frequency of particles below 2.5 μm seemed not to be affected by the altitude. In general, the regional dust loading and characteristics are subject to significant spatio-temporal variability. This finding necessitates more systematic observations at as many locations as possible around the Hamoun basin in order to improve the understanding of forcing dynamics, transport mechanisms as well as to quantify the dust amounts emitted from the Hamoun basin.

Dust mineralogy and geochemical properties were examined in the Sistan region by collecting airborne samples at two stations and soil samples from several locations around Sistan and Hamoun basin in order to understand their characteristics and the potential impact on human health. The Sistan region is an ideal site to study the nature of dust storms as it receives large amounts of fine alluvial material from extended rivers system draining much of the Afghanistan highlands, which comprise crystalline basement rocks, Phanerozoic sediments and extensive flood basalts. As a result, large quantities of quartz-rich, feldspar- and mica-bearing silt, as well as mafic material from flood basalt sources and carbonate minerals from dolomites are transported to the Hamoun wetlands in

northern Sistan. Due to droughts at Hamoun and large irrigation projects upstream on the river catchment, extensive desiccation has occurred in the wetlands resulting in large dry lake environments. These have produced large quantities of evaporate minerals to add to the alluvial silts, and the combination of these materials provides the provenance for the airborne dust.

Dust aerosol characterization included chemical analysis of major and trace elements by XRF and mineral analysis by XRD. The results showed that quartz, calcite, muscovite, plagioclase and chlorite are the main mineralogical components of the dust, in descending order, over Sistan, and were present in all the selected airborne dust samples. In contrast, significantly lower percentages for enstatite, halite, dolomite, microcline, gypsum, diopside, orthoclase and hornblende were found, since these minerals occurred only in some of the samples at both stations. On the other hand, SiO2, CaO, Al2O3, Na2O, MgO and Fe2O3 were the major elements characterising the dust, while large amounts of F, Cl and S were also found as trace elements. The mineralogy and chemical composition of airborne dust were nearly the same and quite similar to the soil samples collected at several locations downwind. This suggests that the dust over Sistan is locally emitted, i.e. from the Hamoun basin, and in a few cases can also be long-range transported. On the other hand, individual dust storms showed significant differences between either evaporite-dominated aerosols or those characterized by deflation from alluvial silts. These possibly reflect either localized climatic cyclicity or desiccation cycles. However, in some cases the soil samples showed poor comparisons with aerosol compositions, suggesting that dynamic sorting, soil-forming processes and climatic influences, such as rainfall, altered the mineralogy and chemistry in these partially Aeolian deposits. Sistan is also an ideal site for studying dust storms and enrichment factors relative to crustal norms; the latter factors suggest that the dust is essentially of crustal rather than anthropogenic origin.

For monitoring dust production and effects of regional-scale atmospheric processes on dust emission and transport over the Sistan, satellite remote sensing provided observational constraints. The aerosol patterns were analysed by means of multiple satellite platforms aiming to reveal the spatio-temporal and vertical distribution of dust aerosols. The main focus is to determine similarities and differences in dust climatology provided by these sensors over the Sistan region and surroundings. AI and AOD were used as measures of the atmospheric aerosol load. The analysis used the strength of each

data set separately to provide a general picture on how the aerosols vary across different regions of southwest Asia and how this variability relates with the atmospheric conditions. The results showed a marked seasonal cycle with high aerosol loading during summer and lower in winter, while MISR, MODIS Deep Blue and OMI climatologies agree in both terms of monthly and seasonally mean spatial and temporal aerosol patterns revealing similar seasonal behavior over the region. After prolonged drought conditions in 1999 at Hamoun lakes (northern of Sistan) the dust-aerosol load over the area has increased. The higher aerosol concentrations during summer are interpreted as a result of the Levar northerly winds and the drying of Hamoun lakes. The satellite monitoring highlights Sistan and Hamoun basin as major dust source regions in south Asia, spreading dust aerosols over Afghanistan, Pakistan and Arabian Sea.

7.2 Future work

The unique research and finding in this thesis, over Sistan region needs to be continued and expended with the aim of examining dust storms in the regions and their influence on human health, ecosystems, ocean color and phytoplankton as well as examining the optical and physical properties of dust in a more comprehensive way by means of new established ground-based instrumentation, such as sun photometers, lidars, etc.

Dust storms over Sistan basin are a challenging issue for the region. There are no meteorological stations in the Afghanistan part of Hamoun and only a few in Iran and Pakistan. To fully understand the issues mentioned above, co-operative work with the governments of Afghanistan, Iran and Pakistan is recommend to stablish a network of ground-based data measurements, which have to be integrated and compared with satellite observatory data. Future work needs to also focus on the dried lakes of Hamoun Jazourian between Sistan and Arabian Sea. The methodology of this dissertation can be applied to provide regional dust characterization, and seasonal and interannual variability.

The dust flux loading, mineral and chemical characterizations were analyzed using samples only at the ground surface up to 8 m height and at two stations, due to remote region and lack of established towers and measurement samplers as well as financial aid

for the study period. The characterization of physical, chemical and mineralogy characteristics of dust over a more extended area around Sistan would better reveal the modification of dust properties as it is transported from the source region to downwind areas. Systematic monitoring of the vertical profiles of dust would also be benefical for mode studies over the region.

This research demonstrated that the behavior of dust outbreaks over Sistan depend strongly on the Hamoun dried beds as source regions. Systematic monitoring of dust from satellites and ground-based observations would also anable constitute the basis for model simulations of dust storms over Sistan and Hamoun basin. Furthermore, the chemical and mineralogy composition of dust can be used in radiative transfer models for obtaining the radiative forcing of dust over the whole region.

Measurements for $PM_{2.5}$ and $PM_{1.0}$ concentrations were restricted to Zahedan city, 200 km far away from Hamoun lakes. It is recommended that more systematic observations of particulate matter are necessary over the whole of the Sistan region and, especially in Zabol city and Hamoun dried lakes, in order to compare air quality standards as well as health effects of $PM_{2.5}$ and PM_{10} over Sistan. It is also recommended that the PM_{10} and $PM_{2.5}$ samples collected over Sistan be analyzed using XRF and XRD techniques in order to reveal the chemical and mineralogy composition of the particulate matter (coarse and fine particles).

In addition to TOMS, OMI, MODIS, MISR satellite monitoring over Sistan regions. CALIPSO observations may provide important information about the optical properties of aerosol and its vertical distribution over both the dust sources and downwind regions. By using of CALIPSO data in combination with other aerosol monitoring from space, a more accurate assessment of the impact of dust aerosols on the radiative energy balance and climate over the Sistan Basin can be achieved. With respect to the Sistan climate, implementation of CALIPSO profiles used with regional transport models can be used to improve understanding of how the aerosol's vertical distribution affects the temperature profile, atmospheric heating and stability over the region.